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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 24

WATER RESOURCES OF THE STATE OF NEW YORK
PART I.—RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation, prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888–89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889–90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890–91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; and "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; and "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; and "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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WATER RESOURCES

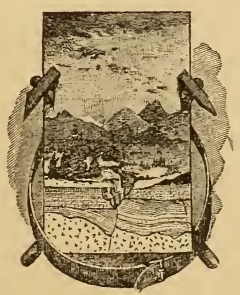
OF THE

STATE OF NEW YORK

PART I

BY

GEORGE W. RAFTER



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CONTENTS.

	Page.
Letter of transmittal	7
Introduction	9
General statements	10
Favorable natural conditions	11
Artificial modifications	11
Water storage	12
Erie Canal	13
Value of water to industries	14
Ownership of water	14
Physical conditions	16
Mountains and forests	16
Temperature and precipitation	18
Rocks and stream flow	21
River systems	23
St. Lawrence system	24
Niagara River	24
Genesee River	25
Oswego River	27
Black River	29
Streams flowing into St. Lawrence River	30
Lake Champlain system	31
Hudson River system	33
Mohawk River	35
Schoharie Creek	35
East Canada Creek	36
West Canada Creek	38
Other tributaries of Mohawk River	40
Hoosic River	40
Battenkill River	40
Fish Creek	41
Sacundaga River	42
Schroon River	43
Tributaries south of Mohawk River	43
Allegheny River system	44
Susquehanna River system	44
Delaware River system	46
Streams of Long Island	47
Available water supply	48
Run-off of Niagara River	48
Run-off of St. Lawrence River	65
Run-off of inland streams of New York	66
Discharge measurements of Eaton and Madison brooks	67
Discharge measurements of Oatka Creek	69
Discharge measurements of Genesee River	70
Discharge measurements of Hemlock Lake	75
Discharge measurements of Skaneateles Lake	77

Available water supply—Continued. Page.
Run-off of inland streams of New York—Continued.
Discharge measurements of Hudson River ... 79
Discharge measurements of Croton River ... 82
Maximum and minimum flow of streams in New York ... 87
Floods in Chemung River ... 87
Low-water flow of Oatka Creek ... 90
Low-water flow of Genesee River ... 90
Low-water flow of Hemlock Lake ... 92
Low-water flow of Morris Run ... 93
Low-water flow of West Branch of Canadaway Creek ... 94
Low-water flow of Skaneateles Lake ... 96
Low-water flow of Oswego River ... 96
Low-water flow of Black River ... 96
Low-water flow of Mohawk River ... 97
Low-water flow of Hudson River ... 97
Low-water flow of Croton River ... 98
Summary of knowledge of low-water flow ... 98
Index ... 100

ILLUSTRATIONS.

Page.
PLATE I. Erie Canal at the city of Buffalo ... 12
II. *A*, Beaver Meadow, near Indian Lake, a typical reservoir site in the Adirondacks; *B*, Bog River in the Adirondacks ... 16
III. Drainage area of Genesee River ... 24
IV. *A*, Upper and Middle Falls of Genesee River, at Portage; *B*, Genesee River Canyon below Middle Falls, at Portage ... 26
V. Middle and Lower Falls of Genesee River at Rochester ... 28
VI. *A*, Dam at the High Falls of East Canada Creek; *B*, High Falls at Trenton on West Canada Creek ... 38
VII. Big Falls of Battenkill River ... 40
VIII. *A*, Hudson River above Luzerne; *B*, Sacundaga River near Luzerne ... 42
IX. Drainage area of Schroon River ... 44
X. Canyon of Genesee River between Mount Morris and Portage ... 70
XI. *A*, Erie Canal aqueduct and south side of Main street bridge, Rochester; *B*, Great flood of 1865 at Rochester, showing lumber lodged against aqueduct bridge ... 90
XII. Upper Falls of Genesee River at Portage ... 92
XIII. High Falls of Mohawk River at time of low water ... 96
FIG. 1. Index map of rivers of New York ... 23
2. Discharge of Genesee River at Mount Morris, New York, 1893 to 1896 ... 73
3. Flood flow of Genesee River, May 18–24, 1894 ... 74
4. Discharge of Hudson River at Mechanicville, New York, 1888 to 1897 ... 81

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, November 26, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Water Resources of the State of New York, prepared by Mr. George W. Rafter, and to recommend that it be published in the series of pamphlets upon Water Supply and Irrigation. The data herewith presented were brought together by Mr. Rafter during 1897 and transmitted early in February, 1898. Publication has been somewhat delayed by various obstacles which could not be readily overcome. The data are, however, of general interest and value, not only to the people of New York State, but also to engineers and persons in all parts of the country interested in the development and utilization of the water resources. Particular attention is given to the discussion of floods and low-water flow, these being to a large extent the determining factors in considerations of the utilization of water power.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF NEW YORK, PART I.

By George W. Rafter.

INTRODUCTION.

The preeminent position of the State of New York is due almost entirely to her great natural water resources. Reaching from the ocean on the east to the Great Lakes on the west, she has gathered to herself the treasures of the foreign world as well as those of half the Western Continent. Her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth. Taking into account the commercial supremacy guaranteed by the Erie Canal, it may be said that the history of the State's progress during the nineteenth century is largely a history of the development of her water resources. It is the purpose of the author in this report to relate briefly not only in what manner these resources have been employed, but to indicate the recent lines of development and the probable future of the State if her water is utilized to the fullest degree. It is proposed to describe in a general way the river systems, giving brief descriptions of several of the more important utilizations of water in New York, together with a discussion of some of the economic problems confronting the people of the State.

As regards the water power of New York, it may be noted that the Tenth Census of the United States, 1880, Vols. XVI and XVII, gives in great detail the statistics of the main water powers as they existed in 1882. Many of these show considerable increase at the present time, although the new works are for the most part similar to those described in the census report, and hence present few additional features of interest. Several of the recent plants, however, are on quite different lines both as to their scope and as to the method of development adopted. It has therefore seemed more important to describe a few of the new plants and to give the main facts of the great storage projects of the Hudson and Genesee rivers than to spend time on small and relatively unimportant powers.

The peculiar relation of the State to water-power development on the main rivers of New York should be here mentioned. Owing to the circumstances of the early settlements and the development of the canal system, the State has assumed ownership of the inland waters, or, at any rate, of all streams used as feeders of the canals. This assumption has worked injustice to riparian owners, and is at present a bar in the way of the full development of important streams by private enterprise.

The data embodied in this report have been gathered from many sources—the annual reports of the State engineer and surveyor, the superintendent of public works, the forest commission, the State board of health, the State weather service, and other public documents. The data in the reports on the Water Power of the United States, Tenth Census, have been used in many cases where later data are not available. During the years 1896 and 1897 the author, in addition to his regular duties in the State engineer's department, gathered a large amount of information bearing on the water resources of the State and not published in the annual reports of the State engineer's department. Much of this is in the way of piecing out earlier information and bringing the subject up to date. By the courtesy of the State engineer and surveyor these special data have been embodied in the present report.

The figures as to drainage area have been obtained by checking on French's map, published in 1860, those given in the reports on the water power of the United States, Tenth Census, so far as they are available, and by planimeter measurement on the topographic atlas sheets of the State made by the United States Geological Survey. Bien's Atlas of the State of New York has also been used as a check in some cases, and a number of areas have been taken from the report of the Deep Waterways Commission.

The elevations of points above tide water have been compiled from all available sources of information, such as Dictionary of Altitudes in the United States, Bulletin No. 76 of the United States Geological Survey; the reports of the New York State survey and railway canal profiles; the topographic atlas sheets of the United States Geological Survey, and the reports on the water power of the United States, Tenth Census, 1880.

GENERAL STATEMENT.

A report of this character is prepared for the benefit of two classes: First, professional or business men who read during leisure hours in order to add to their stock of general information; second, engineering specialists, physicists, and men of expert scientific attainments generally who desire full details as part of their stock of professional knowledge. The latter class will naturally study the details, while

for the former a succinct statement of the results of the study is generally sufficient. It is from this point of view that a statement of the general results of the study of the water resources of New York is here introduced at the beginning of the report.

FAVORABLE NATURAL CONDITIONS.

New York State is great in water resources, not only by virtue of her position between the Atlantic Ocean and the Great Lakes, but because topographic, geologic, and climatic conditions have combined to make her the highway of commerce as well as the manufacturing center of the United States. Some of the contributing causes to this preeminent position may be found in her mountain systems, affording three great water centers, from which large streams descend to the neighboring lowlands, affording large opportunities for the economic development of water power. As regards water power, the other chief contributing causes are the possession, as part of her domain, of Niagara and St. Lawrence rivers, with their extensive possibilities for future water-power development.

A study of the climatology of New York shows that in nearly every portion of the State the amount and distribution of the rainfall are such as to insure a large enough run-off of streams to furnish, even under natural conditions, considerable water power.

ARTIFICIAL MODIFICATIONS.

Natural conditions have been largely interfered with by the cutting off of forests and the consequent extensive development of the agricultural interests of the State. As a tentative proposition, it is assumed that the general cutting off of the forests of New York State has decreased the annual run-off of streams issuing from the deforested areas to a depth of from 4 to 6 inches per annum.

The run-off of Niagara River has been commonly assumed, on the authority of the Lake Survey, at about 265,000 cubic feet per second. The recent studies indicate that the extreme low flow of a cycle of minimum years may be not more than 60 per cent of this figure. From this point of view the people of the State of New York have the greatest possible interest in any project which would tend to decrease the low-water run-off of that stream. Such interest is equally pronounced in the case of St. Lawrence River.

Measurements of discharge of a number of the inland streams of New York indicate considerable variations in water yield in different parts of the State. For instance, Genesee River, in the western part, in 1895 gave, with a rainfall of 31 inches, a minimum flow for the year of 6.67 inches. The drainage area of this stream is mostly deforested, whence it results that serious floods are frequent. For

example, from May 19 to 24, 1894, the total discharge was nearly 6,900,000,000 cubic feet, the maximum, which occurred at 3.30 a. m., May 21, being 42,000 cubic feet per second. The drainage area above the point where this flood occurred is 1,070 square miles.

The lowest annual run-off thus far measured in the State of New York is that of the Hemlock Lake drainage area, where, in 1880, the total run-off from an area of 43 square miles was only about 3.35 inches.

Oswego, Mohawk, and Hudson rivers and their tributaries in this State all have large pondage on natural lakes, which, with other conditions, tend to maintain the low-water flow. Croton River presents surface geological conditions which tend to increase its low-water flow. Without going into detail, we may say that these streams will yield a minimum flow of about 0.3 of a cubic foot per square mile per second. Variations from this limit are given in the chapters specially discussing minimum flow.

As a typical flood stream of the State, Chemung River may be mentioned, where serious floods, due to deforestation of a mountainous drainage area, have become so common as to necessitate the carrying out of extensive protection works at the large towns on that stream.

WATER STORAGE.

Large development of water power on Genesee River has led to a demand for extensive storage reservoirs on that stream. The surveys made by the State indicate that a storage reservoir of 15,000,000,000 cubic feet capacity can be constructed at a cost of $2,600,000, or at the rate of about $173 per million cubic feet stored. It is considered that the construction of such a reservoir is commercially feasible, and, provided the State legislature will grant the necessary permission, the project will probably be carried out by a private company. The developed water power of Genesee River has increased from about 6,000 horsepower in 1882 to about 18,000 horsepower in 1898.

Extended studies have also been made of the possibilities of water storage on Hudson River, where the water power has increased from less than 13,000 horsepower in 1882 to something like 55,000 horsepower at the beginning of 1898. The studies, so far as carried, show that it is possible to create on that stream a continuous, permanent power of about 175,000 horsepower. Probably when the studies are complete it will appear that considerably more than this can be developed at a cost which will be commercially feasible.

The great power developments on Niagara River at Niagara Falls, and on St. Lawrence River at Massena, are the most significant industrial movements now taking place in the United States. The future power of these two streams may easily be placed at several hundred thousand horsepower.

ERIE CANAL AT THE CITY OF BUFFALO.

ERIE CANAL.

Erie Canal, a view of which is given on Pl. I, was the first great development of the internal water resources of New York, and grew out of the demand for transportation facilities between the Atlantic seaboard and the Great Lakes. The impulse which it gave to the development of New York State, and of the entire territory tributary to the Great Lakes, can hardly be estimated. Taking into account its far-reaching consequences, it may be considered the greatest public work thus far carried out in the United States. Nevertheless, Erie Canal has not only passed its day of usefulness, but, to some extent, stands in the way of future development, the chief cause for this being a too pronounced regard for the canal's former greatness. The historical matter cited in the body of the report may serve to indicate how strongly the feeling that Erie Canal should be maintained in perpetuity has been impressed upon the people of the State of New York.

By way of illustrating the rise and decline of Erie Canal, it may be cited that in 1837 the total freight carried was 1,171,296 tons, valued at $55,809,288; in 1880 the total freight carried was 6,457,656 tons, valued at $247,844,790; in 1895 the total freight carried was 3,500,314 tons, valued at $97,453,021. Statistics show that the great bulk of all the freight now carried on Erie Canal is through freight carried for Western producers, local business being only a small per cent of the whole. Statistics show that freights are now carried by railways as cheaply as they can be carried by the canal, and this, too, at a profit, while the canal, in order to obtain any freight at all, has been obliged to do away with all tolls, thus making the cost of shipment by canal the bare cost of transportation proper.

In 1895 an improvement of Erie Canal was authorized at a cost of $9,000,000. The work of this improvement is now in progress. Recently it has been found that the cost will be $16,000,000, instead of $9,000,000, as originally expected. On this basis, and throwing out of the account former expenditures, we may say that Erie Canal will cost the people of the State of New York annually at least $1,230,000. Assuming a traffic for the enlargement of the canal of 5,000,000 tons per annum, carried 200 miles, we have a total of 1,000,000,000 ton-miles per annum on which the people of the State of New York must pay in the way of interest and cost of maintenance and operation about 1.25 mills per ton-mile, while canal freights now average about 1.2 mills per ton-mile; hence the people of the State of New York will be obliged to pay under the new conditions over 50 per cent of the total cost of the transportation. At present the local canal freights are only 15 per cent of the total.

Owing to her extensive inland-navigation system the experience of New York as to loss of water from artificial channels has been very

extensive. Measurements made at different times show that in a canal of the dimensions of the original Erie Canal, which had a section of 40 feet water surface, 28 feet bottom, and 4 feet depth, there should be provided, in order to cover the evaporation and percolation losses, a water supply of about 100 cubic feet per mile per minute. Details relating to this special subject may be found further on.

The State early adopted the policy of leasing surplus waters of Erie Canal for power purposes. The most extensive development growing out of such leases is that at Lockport, where several thousand horsepower are in use supplying establishments valued at about $2,500,000 a year, and employing nearly 1,900 operatives, with an annual product of about $3,000,000.

VALUE OF WATER TO INDUSTRIES.

Water power is extensively sold at Oswego, Cohoes, and Niagara Falls, and to some extent at Rochester. It will also be extensively sold at Massena when the development there is completed.

The value of the internal waters of the State to some of the leading industries, such as the lumber industry and the wood-pulp and paper industry, may be noted. On Hudson River from 1851 to 1897, inclusive, the total number of logs taken to market by water transportation was 23,313,585, these market logs furnishing 4,662,717,000 feet B. M. of lumber. The cost of driving logs from the head waters of the Hudson to the Big Boom above Glens Falls is said to be from 50 to 75 cents per thousand feet B. M.

The wood-pulp and paper industry is developed in New York State to a point beyond that reached in any other State of the Union. On January 1, 1898, there were at least 125,000 net water horsepower in use in the State in the production of mechanical wood pulp, while probably from 30,000 to 35,000 more are consumed in operating paper mills.

One obstacle to the easy operation of water power in this State is the formation on many streams of frazil or anchor ice. A study of the formation of frazil and anchor ice, as made by the Montreal harbor commissioners, indicates that it may be possible to learn in the future how to remedy this difficulty.

OWNERSHIP OF WATER.

The sand areas of Long Island present conditions of water yield different from those of the other drainage areas of the State. We have here an extended region of coarse, deep sand, into which the rainfall sinks easily, there being almost no surface run-off. These sand areas form subterranean reservoirs, from which from 0.7 to 0.8 cubic foot per square mile per second may be drawn, the same as from artificial reservoirs on the earth's surface, these natural underground

reservoirs possessing the advantage of furnishing a filtered water of a high degree of purity.

The taking of the water supply of Brooklyn from the sand areas of Long Island has led to the development of legal principles relating to rights in underground water somewhat different from those derived from the common law of England. The decision in a test case now before the courts is, in effect, that when subterranean water is taken in large quantity for the supply of cities or for manufacturing purposes the party taking it is liable to the adjacent landowners the same as in the case of diverting surface water.

Owing to the development of the internal navigation system, and the consequent assumption on the part of the courts and State officials that the State's rights to the inland waters were, in effect, paramount to all other rights, no general mill act has ever been enacted in the State. Nevertheless, the demand for water storage on the streams of the northern part of the State and on St. Lawrence River, which are not in any way tributary to Erie Canal, has led to the enactment of a number of special laws which have the force of mill acts in that they grant the right of eminent domain for the purpose of improving the hydraulic power of streams. This phase of development of the laws of this State relating to riparian rights is an exceedingly interesting one.

Titles to lands under water and water rights have been considerably complicated in New York because of the peculiar circumstances of the early settlement. It is well-established law that Hudson and Mohawk rivers belong to the State, while the Genesee and the other large rivers belong to the riparian owners. A confusion of ideas arising out of such contradictory facts as these has undoubtedly assisted in obscuring the real relations of the State to riparian owners in New York.

In the case of Black River large quantities of water have been diverted for the supply of Black River and Erie Canal, which has been compensated for in kind by the construction of a system of State reservoirs on the head waters of that stream capable of storing nearly 3,800,000,000 cubic feet. The State has further recognized the rights of riparian owners in the Black River reservoirs by creating a commission of owners and users of water power on Black River to manage the discharge from the reservoirs.

Skaneateles Lake presents a case where the State, having originally appropriated water for the supply of Erie Canal, has later, by act of legislature, allowed the taking of the said water for a municipal supply.

With restrictive legislation repealed and a proper mill act enacted, we may hope ultimately to develop in New York approximately 1,518,000 gross horsepower, worth to the people of the State anywhere from $150,000,000 to $200,000,000 a year, or as much as the present entire agricultural product of the State.

PHYSICAL CONDITIONS.

Considering only the broader topographic features, the streams of the State may be pictured as coming from three main water centers. The first of these in importance is the Adirondack area, the peaks of which are over 5,000 feet in height. Next to this are the Catskill Mountains, in the southeastern part of the State, the greatest heights of which are about 4,000 feet; and third are the highlands of the southwestern portion of the State, portions of the Allegheny Plateau. In extent the Adirondack Region is much the largest, and owing to this fact and its higher elevation it is the most important water center of the State. The Catskill Region, from its lower altitude and from changes introduced by cutting off the forests, is much less valuable in yield of water. The issuing streams are flashy and uncertain, pouring down destructive floods in spring and running nearly dry during the summer and fall. It is, without doubt, largely owing to this fact that water-power development has made less progress in this part of the State than in the other power-producing sections. The Allegheny Plateau has also greatly deteriorated in water-yielding capacity on account of deforestation. The serious effect of such decrease is discussed later in connection with the Genesee River storage project.

MOUNTAINS AND FORESTS.

The mountain belt included in the Adirondacks proper—the Bouquet, Schroon, Kayaderosseras, and Luzerne ranges, with the Highlands immediately to the west—has come to be commonly known as the Adirondack Plateau. Describing this broadly, it may be considered as bounded on the east by Lake Champlain, on the west by the valley of Black River, on the north by the farming regions of the St. Lawrence, and on the south by those of the Mohawk Valley. The mountain belt proper, however, occupies only the eastern and southern part of the Adirondack Plateau. Its greatest width is about 40 miles. The mountain ranges, however, are not always distinct; sometimes these are lateral spurs interlocked and sometimes single mountains occupy the space between the ranges, filling the valleys.

From the Adirondack Plateau streams flow to the north, southeast, and west. The principal streams flowing north, east, and west to the St. Lawrence system are Moose, Beaver, Oswegatchie, Grass, Raquette, St. Regis, Salmon, Saranac, Ausable, and Bouquet rivers. The southern streams, which all belong to the Hudson system, are Sacundaga, Indian, Cedar, Opalescent, Boreas, and Schroon rivers, and East Canada and West Canada creeks. All these streams head in lakes, of which the most important, tributary to the St. Lawrence, are Placid, Saranac, St. Regis, Loon, Rainbow, Osgood, Meacham, Massawepie, Cranberry, Tupper, Smiths, Albany, Red Horse Chain, Beaver, Brandeth, Bog

A BEAVER MEADOW, NEAR INDIAN LAKE, A TYPICAL RESERVOIR SITE IN THE ADIRONDACKS.

B. BOG RIVER IN THE ADIRONDACKS.

River Chain, Big Moose, Fulton Chain, Woodhull, Bisby, Raquette, and Blue Mountain. Typical views are given on Pl. II.

Following are the principal lakes of the Adirondack Plateau tributary to the Hudson system: Pleasant, Piseco, Oxbow, Sacundaga, Elm, Morehouse, Honnedaga, West Canada, Wilmurt, Salmon, Spruce, Cedar, Lewey, Indian, Rock, Chain, Catlin, Rich, Harris, Newcomb, Thirteenth, Henderson, Sanford, Colden, Boreas, Elk, Paradox, Brant, Schroon, and Luzerne.

The great forest of northern New York occupies the central part of the Adirondack Plateau, and deserves notice from its importance as a conservator of the streams issuing from that region. According to a map accompanying the report of the forest commissioners of New York for 1891, the outlines of the great forest are substantially as follows: Its eastern boundary coincides quite closely with a line drawn through Keene Valley and thence along the valleys of Schroon River and the upper Hudson; its southern boundary is for the main part identical with that of Hamilton County and the town of Wilmurt, in Herkimer County, although in some places the forest extends a short distance into Fulton County; its western boundary is the county line between Lewis and Herkimer counties; its northern boundary runs in an irregular line from a point near Harrisville, on the Lewis and St. Lawrence County line, to the Upper Chateaugay Lake, which is situated near the line between Franklin and Clinton counties. This territory contains about 3,590,000 acres, of which 3,280,000 acres are considered to be covered with dense forests. Within this region there are from 1,300 to 1,400 lakes and ponds, while from it the eighteen important streams just enumerated diverge in every direction. The general elevation of the Adirondack Plateau is about 2,000 feet above the level of the sea. Little discussion is needed, therefore, to show the great value of this elevated forest-covered plateau as a conservator of the natural waters of the State.

One important utilization of the waters of this State formerly was the carrying of logs to market through the various streams. By reason of the clearing off of the forests, that business has gradually declined, until, except in the Adirondack Plateau, it is now of little importance. It has been the policy of the State for a number of years to acquire, as far as possible, by tax title and purchase, bodies of land in the Adirondack forest for the purpose not only of conserving the forests in order to increase the yield of streams, but for the further purpose of creating a forest park worthy of the great Commonwealth of New York. In order to carry out this project the forest-preserve board has been empowered to purchase lands within the forest, or, failing to agree on terms with the landowners, to take lands under condemnation proceeding.[1]

[1] The State holdings in the Adirondack Region up to the year 1895 may be determined by reference to a map of the Adirondack forest and adjoining territory as issued by the fisheries, game, and forest commission in 1895.

The Adirondack Plateau is a rugged, rocky region, sparsely populated, and worthless for agriculture. Its chief value lies in a complete utilization of such natural resources as attach to its unparalleled water-yielding capacity. From this point of view it may easily become an important factor in the future development of New York. To insure this result the water yield of every stream of the region needs to be conserved by reservoir systems.

TEMPERATURE AND PRECIPITATION.

In 1826 an elaborate system of meteorological observations at the State academies was inaugurated by the board of regents of the University of New York and was continued until 1863. During a portion of this period, and later, a large amount of data was obtained by volunteer observers of the Smithsonian Institution and at military posts. In 1871 the United States Signal Service took charge of work of this character, and in 1889 the State meteorological bureau was organized. There is, therefore, a large accumulation of material regarding the local climate, such that an account of it would extend beyond the limits of this paper. For details reference should be made to the volumes on meteorology published by the board of regents of the State University; also to the bulletins and annual reports of the State meteorological bureau and of the United States Weather Bureau.

To facilitate the study of meteorological data the individual stations have been grouped in accordance with topographic features and geographic position, the subdivisions being as shown in the accompanying table. The names indicate in a general way the relative position, the Western Plateau including the portion of the Appalachian Highlands west of Seneca Lake, and the Eastern Plateau the remainder of the Appalachian Highlands from Seneca Lake eastward to the Hudson Valley.

The average annual temperature is generally taken as decreasing with altitude at the ratio of 1° F. to every 300 feet of elevation, the rate being somewhat below this average in winter and above it in summer. An approximate determination for the State indicates that the rates of decrease are .3° F. per hundred feet elevation for the winter, and .4° F. per hundred feet for the summer. For the mountains of northern New York a much smaller variation than .3° F. appears to hold for the winter months.

Average monthly and annual temperatures for the 22-year period, 1871–1892. (*a*)

	Western Plateau.	Eastern Plateau.	Northern Plateau.	Atlantic coast.	Hudson Valley.	Champlain Valley.	St. Lawrence Valley.	Great Lakes.	Central lakes.	Mohawk Valley.	Average of the ten regions.
Altitude (feet)	1,287	1,070	1,578	82	221	186	431	484	645	639	662
January	22.0	21.3	16.0	30.5	21.5	16.3	15.9	23.4	24.2	21.0	21.6
February	23.6	22.5	16.8	31.6	26.9	17.5	17.3	24.3	25.8	22.8	22.9
March	28.5	28.6	24.0	35.9	38.2	25.9	26.5	29.9	30.6	28.8	29.2
April	41.7	42.0	36.8	46.7	46.2	40.8	40.4	42.0	44.2	42.8	42.3
May	54.8	55.0	57.8	57.6	58.8	55.2	55.5	54.8	57.3	55.8	55.7
June	64.3	64.8	60.3	67.0	68.1	64.7	64.2	64.9	66.0	65.0	65.0
July	68.6	68.6	63.8	72.3	72.0	69.9	68.2	69.8	70.8	69.2	69.3
August	66.6	66.3	62.5	71.1	69.6	67.5	65.9	68.1	68.7	67.3	67.4
September	59.3	61.5	55.0	65.3	62.8	58.6	58.4	61.1	61.6	60.0	60.4
October	47.3	47.2	43.3	55.1	50.8	46.9	45.7	49.3	49.6	48.0	48.3
November	35.5	35.6	31.0	43.9	39.0	34.5	33.2	37.3	37.1	35.0	36.3
December	26.7	25.9	21.2	34.5	28.5	21.8	22.2	28.4	28.3	25.8	26.3
Average	44.8	44.7	40.3	50.8	48.4	43.2	42.8	46.0	47.0	45.2	45.4

a From fifth annual report of the State weather bureau.

The intimate relation which exists between air circulation and precipitation in New York is one of the most interesting facts to be noted. Owing to lack of moisture in the continental interior, northwest winds in the spring, summer, and fall are essentially dry. In winter their dryness proceeds from low temperature and consequent small vapor-carrying capacity. The winter precipitation is due almost entirely to storm areas passing either actually across or in the vicinity of this State and deriving their supply of vapor from the inflow of moist air which they induce, either from the Atlantic Ocean or from the Gulf Region.

The winter months—December, January, and February—have somewhat less precipitation than either of the other seasons, although in the vicinity of the Atlantic coast, on the southwestern highlands of the State, and in the region of the Great Lakes the winter precipitation is relatively large.

In the spring rising temperature produces a modification and shifting of pressure systems, the winds decreasing in velocity and their directions being more variable than in winter. The frequent showers occurring in April and May appear to be due more than at any other time to the effect of an admixture of air having different temperatures.

In summer the Gulf of Mexico and the Atlantic Ocean contribute large supplies of moisture to northward-moving air currents, and, although cyclonic depressions are less frequent than at any other season, the rainfall accompanying each storm is heavy, and in New York the maximum seasonal precipitation, amounting as an average for the whole State to 10.96 inches, occurs in this season.

As regards the fall months, the rainfall of September is usually light in the region east of the Great Lakes, while in October the maximum general rainfall occurs. As regards meteorological conditions, winter may be considered as beginning in November.

Average precipitation in New York State, in inches.

	Western Plateau.	Eastern Plateau.	Northern Plateau.	Coast region.	Hudson Valley.	Champlain Valley.	St. Lawrence Valley.
Altitude (feet) *a*	1,307	1,056	973	132	230	262	414
January	2.52	2.52	3.11	3.47	2.89	1.73	2.19
February	2.23	2.34	2.78	3.22	2.26	1.35	2.15
March	2.51	2.46	3.06	3.74	2.88	1.94	2.49
April	2.68	2.80	2.66	3.50	2.82	1.88	2.21
May	3.36	3.54	3.45	3.90	3.53	2.63	2.82
June	4.23	4.16	3.28	3.53	3.68	3.16	3.54
July	3.25	4.04	4.09	4.20	4.24	3.24	3.39
August	3.13	3.50	3.50	4.54	3.69	3.39	2.75
September	2.90	3.13	3.19	3.59	2.90	3.09	3.26
October	3.28	3.31	3.47	3.93	3.52	3.12	3.44
November	2.76	2.81	3.48	3.87	3.15	2.61	2.71
December	2.73	2.82	2.90	3.44	2.89	1.92	2.57
Annual	35.58	37.43	38.97	44.93	38.46	30.06	33.52
Storage period	16.03	16.49	17.96	21.29	17.27	11.44	14.43
Growing period	10.61	11.69	10.87	12.27	11.62	9.79	9.68
Replenishing period	8.94	9.26	10.14	11.37	9.57	8.83	9.41

a Average altitude of stations considered.

A study of the data shows that there are a number of contending forces which are distinctively operative in New York, and which by modifying one another tend to produce numerous irregularities of the rainfall. So irregular indeed is the precipitation that frequently places only a short distance apart show wide variations.

In a general way it may be said that the amounts of annual rainfall in different sections of New York are mainly determined by proximity to sources of vapor or to vapor-laden air currents, and by the character of the local topography. As regards the latter statement, a more definite form would be that under similar conditions the pre-

cipitation is in some degree proportionate to the altitude. This rule, while generally true, does not apply to the valley of Hudson River, where the upper portion, including the Champlain Valley, receives a somewhat deficient rainfall as compared with the State as a whole. To the west, the Adirondack Plateau receives a marked increase of rainfall, while farther northwest there is a decrease in the valley of the St. Lawrence. This is also true of the elevated region in the vicinity of Hemlock Lake, which, although several hundred feet higher, has a rainfall considerably less than that at Rochester.

In the southeastern portion of the State the ocean winds find no obstruction along the coast, but, passing inland and meeting the abrupt ranges of the southeastern counties, give a copious rainfall, as compared with that of the intervening regions.

Western New York, on account of the frequent southwesterly direction of the winds, receives an appreciable portion of its vapor supply from the Gulf of Mexico. The rainfall in central New York, although less than that of the southeastern and southwestern highlands, is generally abundant. The principal valleys of the Susquehanna system, and also the depression of the central lakes tributary to Oswego River, show a deficiency as compared with the average of the State.

A knowledge of the snowfall is important in a study of the water resources, because by reason of the snow lying on the ground continuously for several months it is a great source of loss in open regions subject to severe winds, the evaporative effect of the winds tending to carry away large quantities of moisture which would otherwise be available to maintain stream flow. Thus far the only data relating to depth of snow are those derived from the reports of the State meteorological bureau. The following are a few figures so derived: In the winter of 1891–92 the total depth of snow at Humphrey, in the Western Plateau, was 119.8 inches; in 1890–91 the total depth at Cooperstown, in the Eastern Plateau, was 110 inches; in 1891–92 the total depth at Constableville, in the Northern Plateau, was 170.7 inches; in the winter of 1890–91, at Utica, in the Mohawk Valley, the total depth was 165 inches, and in 1891–92, at the same place, 151.6 inches. The records show that at the places where these large snowfalls occurred the ground was continuously covered with snow for several months. If the winds were of high velocity at the same time the evaporation loss must have been very great.

ROCKS AND STREAM FLOW.

Among the principal factors affecting stream flow should be noted the structure and texture of the rocks, especially those of the surface. For example, in regions with stiff, heavy, compact soils a much larger proportion of the rainfall runs off on the surface, passing immediately into the streams, than is the case in regions with open, porous soils or extensive sandy areas. A general knowledge of the surface geology

is therefore desirable in a study of the water resources of the State. The relative position and area of the different geologic formations are best shown on the large geologic map of New York prepared under the direction of James Hall, State geologist, by W. J. McGee, and printed by the United States Geological Survey in 1894 (scale, about 5 miles to the inch). A similar but smaller map showing essentially the same features was also printed in the same year under authority of the regents of the university to accompany the report on the mineral exhibit of New York at the World's Columbian Exposition, this being on the scale of approximately 14 miles to an inch. On examining either of these maps one will note the preponderance, so far as area is concerned, of two classes of rocks—the ancient crystallines, which cover a large area in the northern part of the State, and the conglomerates, sandstones, and shales of the Devonian, which form the greater part of the Appalachian Plateau, stretching from Lake Erie across the State to within a short distance of Hudson River, this being the area classified by the State weather bureau as the Eastern and Western plateaus. The streams from the northern crystalline area undoubtedly furnish the best water supply of the State. This may not be due wholly to the character of the rocks, as many other factors contribute to this result.

The sandstones of the Upper Devonian along the northern boundary of Pennsylvania are bounded on the north by the long narrow belts of outcrop of the underlying rocks stretching in a general easterly and westerly direction. The streams pursuing a general northerly course pass in succession across these. As a rule, the soils of the region are heavy, with considerable clay, and the rainfall being absorbed somewhat slowly, a considerable portion of it flows directly into the water courses. The primeval forest has for the most part been cut away and heavy floods are common, such as those of the Genesee and Chemung rivers, described more fully on a later page.

The only streams of this region on which extensive discharge measurements have been made are Genesee River and its tributary, Oatka Creek. Streams of similar character in western Pennsylvania, however, have been measured for a number of years by the Philadelphia water department, and the results of these measurements are available for comparison and discussion. The results obtained on the Pennsylvania streams, the Neshaminy, Tohickon, and Perkiomen, are applicable particularly in estimates of the flow of the tributaries of Delaware River, rising in New York State, and to the more easterly streams which form the Susquehanna.

The drainage basins of the Oswego, Mohawk, and Hudson rivers are so highly composite as regards geologic formations and embrace such a wide variation in topography and surface geology that no definite deductions concerning the effect of the formations on water flow have been drawn. The streams of Long Island, rising among the sands,

tills, and gravels of comparatively recent, unconsolidated formations, offer peculiar conditions, which are discussed on a later page.

RIVER SYSTEMS.

The rivers of the State may be classified into seven general systems, whose relative position is shown by the accompanying index map, fig. 1. These are:

(1) St. Lawrence system, which includes all waters draining to Lakes Erie and Ontario, and Niagara and St. Lawrence rivers.

FIG. 1.—Index map of rivers of New York.

(2) Champlain system, including all streams in the State tributary to Lakes Champlain and George. The Champlain system is in reality a subdivision of the St. Lawrence, but made separate here merely for convenience in discussing the river systems of the State.

(3) Hudson River system, including all streams tributary to the Hudson and its main branch, the Mohawk.

(4) Allegheny River system.

(5) Susquehanna River system.

(6) Delaware River system.

(7) The streams of Long Island tributary to Long Island Sound and the Atlantic Ocean.

The head waters of the branches of Housatonic River in Connecticut flow out of the State to the east, while the head waters of Ramapo River, in Rockland County, flow from New York into New Jersey. These latter are of possible future importance by reason of the necessity of water for the supply either of Greater New York or, in the case of Ramapo River, also for the municipalities of northern New Jersey. Chateaugay River, a tributary of the St. Lawrence, also flows northward into the Dominion of Canada.

ST. LAWRENCE RIVER SYSTEM.

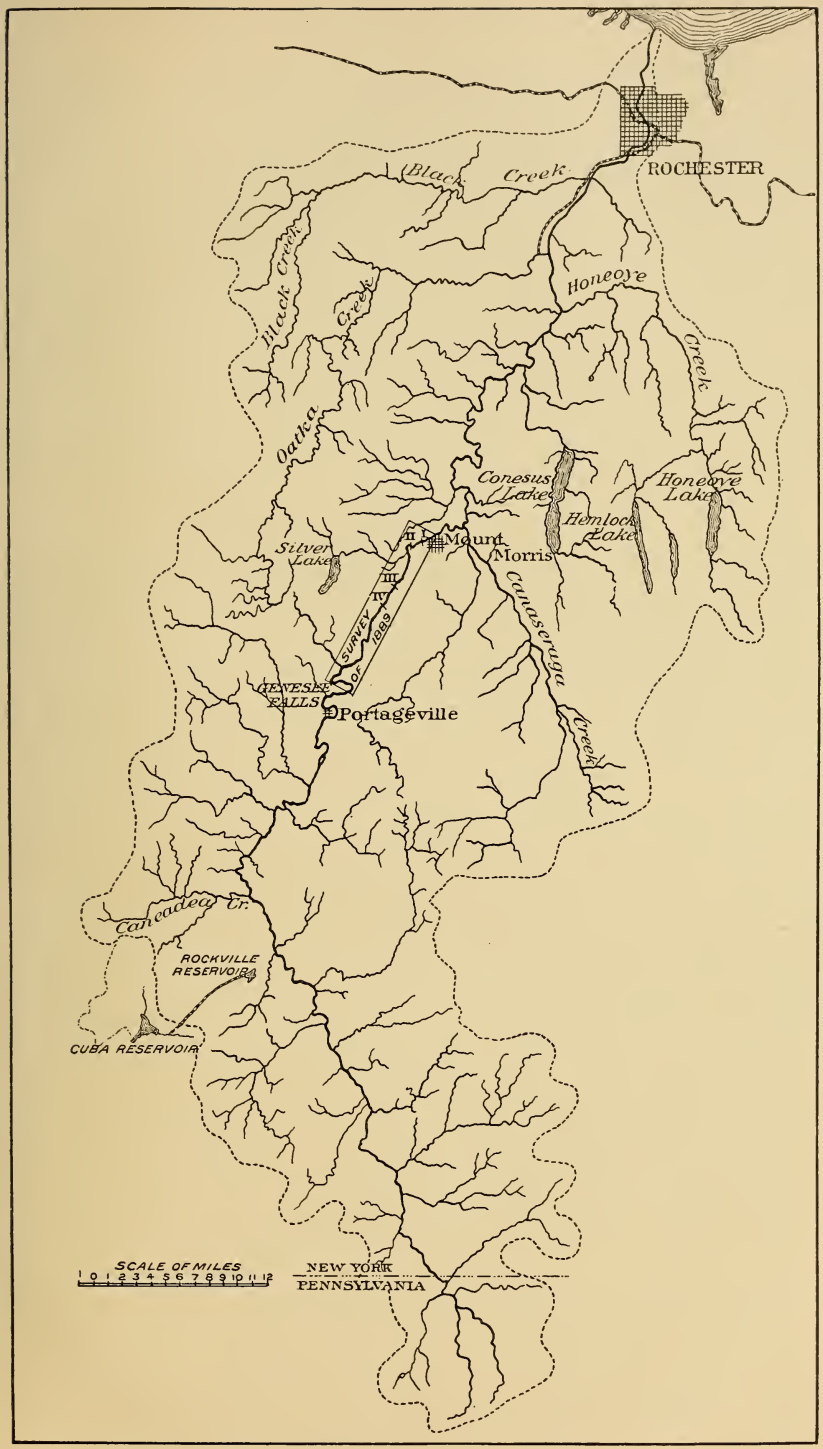
This group embraces the streams tributary to Lake Erie, Niagara River, Lake Ontario, and St. Lawrence River. On the extreme southwest, in Chautauqua County, the watershed line approaches within a few miles of Lake Erie, but at an elevation of several hundred feet above, and as a consequence the streams are short and rapid. A small amount of power is developed on Chautauqua Creek at Westfield, and on Canadaway Creek near Fredonia. Cattaraugus, Buffalo, Tonawanda, and Oak Orchard creeks may also be mentioned as tributaries of Lakes Erie and Ontario and Niagara River in western New York. Buffalo Creek is important as forming a large portion of Buffalo Harbor at its mouth. Tonawanda Creek, which flows into Niagara River at Tonawanda, is used for several miles as a part of Erie Canal. This stream is sluggish throughout nearly its whole course and affords only a small amount of power. The water supply of the village of Attica is taken from its head waters.

NIAGARA RIVER.

Niagara River forms a portion of the boundary between the Dominion of Canada and the State of New York. The difference in elevation between Lakes Erie and Ontario is, approximately, 336 feet, of which about 160 feet are at Niagara Falls. Between Lake Erie and Niagara Falls the river divides into two channels around Grand Island, which is 10 miles long and 4 or 5 miles wide. The general course of the river is from south to north, but in passing around Grand Island the eastern channel bends westward, and for 3 miles from the foot of the island the course of the river is west.

Goat Island lies at the foot of this westerly stretch. On the New York side the American channel finds its way around the island to the American Falls, which break over the rough ledge at right angles to the main river. The Horseshoe Falls, on the Canadian side, are about 3,000 feet higher up and lie between the west end of Goat Island and the Canadian shore. At the Canadian Falls the main river again turns to the north and pursues that general course to Lake Ontario.

The elevation of the water surface at the head of the rapids above the falls is 560 feet above tide water, thus giving a fall from the Lake



DRAINAGE AREA OF THE GENESEE RIVER.

Erie level to that point of from 12 to 13 feet, of which from 4 to 5 feet are included in the rapids at the city of Buffalo, in front of and just below Fort Porter. The descent in the river from the head of the rapids to the brink of the falls is about 50 feet. At the narrows, half a mile above the whirlpool, the elevation of the water surface is 300 feet, while that of the surface of the still water opposite Lewiston is 249 feet; the fall in this section, which is from 4 to 4.5 miles in length, may therefore be taken at 51 feet, while from Lewiston to the mouth at Fort Niagara the fall is only 2 feet in a distance of 7 miles. The total length of Niagara River is about 37 miles.

On account of the immense water-power developments now taking place at Niagara Falls the run-off of Niagara River must necessarily receive extended discussion in a complete account of the water resources of New York.

GENESEE RIVER.

Genesee River, as shown on Pl. III, issues from the highlands of the Allegheny Plateau in Potter County, Pennsylvania, a few miles south of the New York State boundary. Entering Allegany County, it first runs northwesterly for upward of 30 miles to near the village of Canadea, at which point it turns northeasterly, this direction being generally maintained to the mouth. It flows entirely across the county of Allegany and then for several miles forms the boundary between Livingston and Wyoming counties, after which it crosses the northeast part of Livingston into Monroe County, through which it continues to its mouth at Charlotte. Above Portage its course from the State line is chiefly through an alluvial valley.

From Portage to Mount Morris the river flows through a deep and in some places narrow canyon for a distance of over 20 miles. The Portage Falls, with a total descent including the intervening rapids of about 330 feet, are at the head of this canyon. The Upper Portage Falls have a descent, including the rapids, of about 70 feet. Half a mile below are the Middle Falls, shown on Pl. IV, with a descent of 110 feet; while 2 miles below begin the Lower Falls, consisting of a series of rapids about half a mile long with an aggregate fall of 150 feet. These three falls may be taken as aggregating about 270 feet, exclusive of the rapids. At present no power developments exist. Formerly a sawmill was located at the Middle Falls, but on account of the extinction of the lumber business on the stream it has not been operated for many years.

At Mount Morris, Genesee River issues into a broad, level, alluvial valley from 1 to 2 miles wide, which continues to near Rochester, where there is a descent of 263 feet in about 3 miles. The Upper Falls at Rochester, 90 feet in height, are a cataract in the Niagara limestone, while at the Lower Falls, 94 feet in height, shown on Pl. V, the Medina sandstone appears.

The principal tributaries of Genesee River are Canaseraga, Hone-

oye, and Conesus creeks from the east, and Oatka, Black, and Wiscoy creeks from the west. Honeoye, Canadice, and Hemlock lakes are tributary to the Honeoye Creek, and Conesus Lake to Conesus Creek. Silver Lake is another small body of water in the Genesee Basin and tributary to the river by the Silver Lake outlet. Canaseraga Creek joins Genesee River near Mount Morris. From Dansville to its mouth, a distance of 16 miles, this creek flows through a broad alluvial valley with very little fall. Above Dansville the stream is more rapid, but the comparatively small, deforested drainage area limits its value for water power. Honeoye Creek, which is the outlet of Honeoye, Canadice, and Hemlock lakes, furnishes some water power. There are also several mills on the outlet of Conesus Lake.

Formerly there were a number of mills on the Silver Lake outlet, but changed business conditions have led to their decay. The other tributaries of the Genesee have little significance as mill streams. It appears, then, that the two places of importance on Genesee River, from the water-power point of view, are Portage and Rochester. These will be discussed in detail farther on.

The following table gives the detail of the several subdivisions of the drainage area of Genesee River:

Drainage areas, in square miles, of tributaries of Genesee River.

Creek.	Drainage area.	Area above mouth.	Area below mouth.
Cryder	43.3	99.9	143.2
Chenunda	30.0	181.0	211.0
Dykes	68.3	214.0	282.3
Vandemarck	21.6	301.3	322.9
Knights	22.3	323.9	346.2
Phillips	32.3	372.8	405.1
Van Campens	55.7	410.4	466.1
Angelica	82.1	481.1	563.2
White	15.9	569.2	585.1
Black	31.1	595.5	626.6
Crawford	11.8	637.6	649.4
Caneadea	63.3	651.0	714.3
Cold	41.0	745.3	786.3
Rush	35.3	787.0	822.3
Wiscoy	108.6	833.6	942.2
Wolf	19.3	974.9	994.2
Silver Lake	30.4	1,029.2	1,059.6
Coshaqua	82.0	1,059.6	1,141.6
Canaseraga	258.7	1,148.4	1,407.1
Beards	41.3	1,423.1	1,464.4
Conesus Lake	88.8	1,555.5	1,643.9
Honeoye	262.6	1,675.9	1,938.5
Allens	198.1	1,947.1	2,145.2
Black	211.8	2,168.5	2,380.0

The total drainage area of Genesee River at its mouth is 2,445.6 square miles.

A. UPPER AND MIDDLE FALLS OF GENESEE RIVER AT PORTAGE.

B. GENESEE RIVER CANYON BELOW MIDDLE FALLS AT PORTAGE.

The following tabulation gives the elevation of Genesee River at various points.

Elevation above tide water of Genesee River at various points.

	Feet.
Mean surface of Lake Ontario	247
Crest of the feeder dam in south part of the city of Rochester	510
Low-water surface of river at New York, Lake Erie and Western Railway bridge near Avon	538
Crest of old Mount Morris power dam	605
Water surface just above Upper Falls at Portage	1,080
Water surface at New York, Lake Erie and Western Railway bridge near Belvidere	1,333

The extreme head waters in Potter County, Pennsylvania, are stated to be considerably over 2,000 feet above tide.

OSWEGO RIVER.

Oswego River flows into Lake Ontario at the city of Oswego. Its basin includes the more important of the inland lakes of western New York. Taking the lakes of the Oswego River Basin in order from west to east, their names, elevations above tide, area of water surface, and tributary drainage area at the foot of each lake are as follows:

Elevation and area of lakes of the Oswego River Basin.

Lake.	Elevation above tide.	Area.	Drainage area.
	Feet.	*Sq. miles.*	*Sq. miles.*
Canandaigua	687.0	18.6	175.0
Keuka	720.0	20.3	187.0
Seneca	443.0	66.0	707.0
Cayuga	380.0	66.8	1,593.0
Oswaco	710.0	12.4	208.0
Skaneateles	867.0	12.8	73.0
Otisco	784.0	3.0	41.0
Onondaga	364.0	4.0	267.0
Cazenovia	900.0	2.8	9.0
Oneida	370.0	80.9	1,300.0

The following are the drainage areas of Oswego River and its principal tributaries:

Drainage areas of Oswego River and principal tributaries.

	Sq. miles.
Oswego River at mouth	5,013
Below junction of Seneca and Oneida rivers	4,868
Oneida River	1,420
Seneca River	3,450

The subdivisions of the dainage area of Seneca River are as follows:

Subdivisions of drainage area of Seneca River.

	Sq. miles.
At junction with Oneida River	3,450
At Baldwinsville	3,136
At Montezuma	2,472
Below Cayuga Lake	1,593
At entrance to Cayuga Lake	780
At Seneca Falls	771
Waterloo	745
At foot of Seneca Lake	707
Keuka Lake Outlet	213
Catherines Creek	94

The drainage areas of Cayuga Lake and its tributaries are as follows:

Drainage areas of Cayuga Lake and tributaries.

	Sq. miles.
At outlet	813
Cayuga Inlet, including Cascadilla Creek	173
Fall Creek, not including Cascadilla Creek	152
Salmon Creek	90
Taughanic Creek	60

Clyde River, a tributary of Seneca River, is formed by the junction of Canandaigua Outlet and Mud Creek. The latter stream rises in the southern part of Ontario County and flows first north and then east, uniting with Canandaigua Outlet at Lyons. Clyde River joins Seneca River at Montezuma. The following are the drainage areas of Clyde River and tributaries:

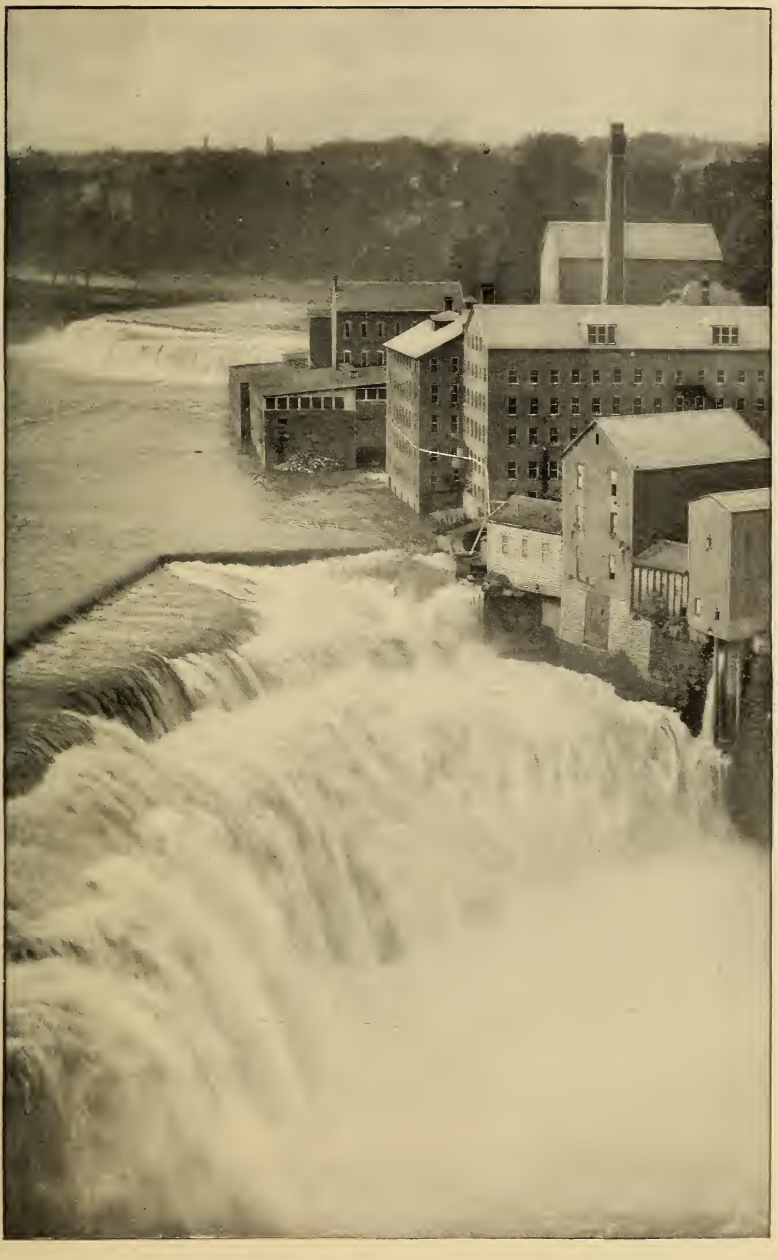
Drainage areas of Clyde River and tributaries.

	Sq. miles.
At mouth	869
At Clyde	807
At Lyons, at junction of Canandaigua Outlet and Mud Creek	729
Mud Creek at Lyons	298
Canandaigua Outlet at junction with Mud Creek	431
Canandaigua Outlet at Phelps	390
Canandaigua Lake at foot	175
Canandaigua Inlet	85

Owasco Lake discharges into Seneca River through an outlet 15 miles in length. The following are the drainage areas of Owasco Outlet:

Drainage areas of Owasco Outlet.

	Sq. miles.
At mouth	230
At Auburn	212
Owasco Lake at foot	208
Owasco Inlet	120



MIDDLE AND LOWER FALLS OF GENESEE RIVER AT ROCHESTER.

The drainage areas of Oneida River and its principal tributaries are as follows:

Drainage areas of Oneida River and principal tributaries.

	Sq. miles.
Oneida River at mouth	1,420
Oneida Lake at foot	1,300
Fish Creek	480
Chittenango Creek, including Cazenovia Lake	306
Oneida Creek	128

The Oswego River and its tributaries furnish a large number of water powers, the detail of which may be obtained from the Report on Water Power of the United States, Tenth Census of the United States, 1880. Very little can be added to the statements in that report.

The next stream of any importance tributary to Lake Ontario is Big Salmon River, which rises in the highlands of Lewis County and flows westerly into Lake Ontario. This stream was extensively considered several years ago as the source of water supply for the city of Syracuse, the water to be taken at a point about 40 miles distant from the city. Its watershed above the proposed point of diversion comprises 70 square miles of forest land at an elevation of from 1,000 to 1,500 feet above tide water.

BLACK RIVER.

Between Big Salmon River and the mouth of Black River there are a number of small streams flowing into Lake Ontario, none of which are of special importance. We may therefore pass to a brief description of Black River. This stream rises in the western part of Hamilton County and pursues a southwesterly direction, passing across Herkimer County into Oneida County; it then bends to somewhat west of north through Lewis County, but soon after passing the northwesterly boundary of that county it changes to a general westerly course, flowing into Black River Bay at the extreme eastern end of Lake Ontario. Extensive water-power developments are in use on this stream and its tributaries, at Watertown, Lyons Falls, Carthage, Black River, Brownville, Dexter, and other points. There are also a number of State reservoirs on the head waters which will be discussed in detail later. The following gives the elevation in feet of the main points on Black River above tide water, according to the best available information.

Altitude of points along Black River.

	Feet.
At mouth	247
Watertown, west line of city	370
Watertown at head of falls	492
Carthage at foot of rapids	669
Carthage at crest of State dam	724

Altitude of points along Black River—Continued.

	Feet.
Lyons Falls at foot	733
Lyons Falls, crest of State dam	802
Forestport, crest of State dam	1,129
North Branch reservoir	1,821
Chub Lake	1,599
Woodhull reservoir	1,854
South Branch reservoir	2,019
Moose River at mouth	802
First Lake, Fulton Chain	1,684
Second Lake	1,684
Third Lake	1,685
Fourth Lake	1,687
Fifth Lake	1,691
Sixth Lake	1,760
Seventh Lake	1,762
Eighth Lake	1,803
Little Moose Lake	1,772
Big Moose Lake	1,787
Beaver River at mouth	724
Beaver Lake at Number Four	1,436

The drainage areas of Black River and its tributaries, in square miles, are as follows:

Drainage areas of Black River and tributaries.

	Sq. miles.
Black River at mouth	1,860
At Watertown	1,820
At Carthage	1,741
At Lyons Falls below Moose River	810
Forestport	275
Above mouth of Sawmill Creek	174
Deer River	107
Beaver River	365
Lovell Creek	34
Independence Creek	90
Martins Creek	29
Otter Creek	60
Moose River	349
Sugar River	66

STREAMS FLOWING INTO ST. LAWRENCE RIVER.

Proceeding along St. Lawrence River we find a number of streams, such as the Oswegatchie, which flows into the St. Lawrence at Ogdensburg; the Grass, which enters the St. Lawrence near the north line of the State; the Raquette and St. Regis, flowing into the St. Lawrence a short distance below the Grass, and finally the Chateaugay, which flows from this State into the Dominion of Canada and thence into the St. Lawrence. These streams all head in and about the Adirondack Plateau and, as a rule, fall rapidly from their sources to near their mouths, affording large water powers, which thus far have

been chiefly utilized for pulp grinding, paper making, and sawing lumber.

There is a lack of definite information in regard to all the streams of the northern part of the State. No detailed surveys of this region have been made. Partial reservoir systems have been constructed on Oswegatchie, Grass, and Raquette rivers. Some of the economic questions involved in the construction of these reservoirs will be discussed in Part II of this paper, Water-Supply Paper No. 25.

So far as can be learned, no measurements have been made of any of the streams tributary to St. Lawrence River proper. It is probable, however, that they are the best water-yielding streams of the State, because they flow from the great northern forest, and because their head waters are in the extensive lake region which lies immediately west of the main Adirondack Mountains, and which extends westward from the base of the main range to the borders of the forest, a distance of nearly 50 miles. This portion of the Adirondack Plateau is comparatively level. As regards geographic distribution, these lakes are most numerous in the northern parts of Herkimer and Hamilton counties and the southern parts of St. Lawrence and Franklin counties. Those in Herkimer County flow into Moose and Beaver rivers, tributaries of Black River. The following are the elevations of a few of the more important lakes of Hamilton, St. Lawrence, and Franklin counties, which are tributary to streams flowing northward into the St. Lawrence:

Elevations of important lakes of Hamilton, St. Lawrence, and Franklin counties.

Lake.	Feet.
Cranberry	1,540
Raquette	1,774
Forked	1,753
Long	1,630
Little Tupper	1,728
Big Tupper	1,552

LAKE CHAMPLAIN SYSTEM.

Lake Champlain has a water area of 400 square miles. The area of its watershed in New York State amounts to 2,950 square miles, in Vermont to 4,270 square miles, and in the Province of Quebec to 740 square miles. The total area of watershed, not including water surface, is 7,960 square miles, or the total area of the drainage basin, including water surface, is 8,360 square miles. Lake Champlain is considered as beginning at Whitehall and terminating at St. Johns, on the Richelieu. Its length is 125 miles and its breadth in the

northern portion about 13 miles. The standard low-water elevation is given at 95.03 feet, and standard high water at 103.78 feet, above tide.

The streams tributary to Lake Champlain are Big Chazy, Little Chazy, Saranac, Salmon, Little Ausable, Big Ausable, and Bouquet rivers and the outlet of Lake George. There are also a few small streams of no special importance.

The streams tributary to Lake Champlain are, as a rule, not of great length, but rising, as they nearly all do, in or near the high mountains of the Northern Plateau they have a rapid descent with an abundant fall. For illustration we may refer to the Saranac River, which has, by the county maps of Bien's Atlas, a length of about 55 miles from its mouth to Lower Saranac Lake. The elevation of Lake Champlain above tide water is 101 feet, while that of Lower Saranac Lake is given at 1,539 feet. Hence the fall in 55 miles of river course is 1,438 feet. Middle Saranac Lake lies at an elevation of 1,542 feet and Upper Saranac at 1,557 feet.

In the case of Ausable River we find a distance by the course of the river of about 40 miles from its mouth to Lake Placid, the elevation of that body of water being 1,864 feet above tide, or 1,763 above Lake Champlain; or, taking the distance by that fork of Ausable River which leads to Ausable Lakes, the distance is about 42 miles to Lower Ausable Lake, the elevation of which is 1,961 feet above tide; hence we have a fall in this stream of 1,860 feet in a little over 40 miles. The water power of the several streams tributary to Lake Champlain has been extensively developed at Plattsburg and other points, as indicated by the tabulations relating to pulp, paper, and lumber interests.

The most southerly tributary of Lake Champlain of any importance for water purposes is the outlet of Lake George, which in about 2 miles has a fall of 222 feet. The greater portion of this is concentrated in the first mile from the lake. The elevation of Lake George above tide water is 323 feet. The area of the lake surface is stated at 50 square miles, and the tributary drainage area above the foot of the lake at 238 square miles. In the absence of accurate topographic maps the drainage area of Lake George, like that of most of the other streams considered, can be given only approximately.

As will be shown later, the streams in eastern New York can not be depended on to furnish a natural flow of more that about 0.3 cubic foot per square mile per second as a minimum in a dry year. On account of the large water surface of Lake George in proportion to the drainage area, it is possible, by utilizing the storage on the lake surface, to realize a much larger quantity. From 0.7 to 0.8 cubic foot per second per square mile may be assumed as a conservative estimate, the results being based on allowing the water to flow out of the lake 24 hours per day for only 310 days in the year. On this

basis we may assume a mean flow for minimum dry years of about 200 cubic feet per second. Since the entire 222-foot fall of the Lake George Outlet is now utilized, we may place the permanent power in a dry year at about 5,000 gross horsepower. The village of Ticonderoga, at which this power is all utilized, had a population in 1890 of 2,267.

Wood Creek, the most southerly tributary of Lake Champlain, is of interest in a study of the water resources of New York, chiefly because of its relations to Champlain Canal, its channel being utilized for several miles as part of the canal. At Fort Ann there is considerable power developed on one of its tributaries, used at present for grinding pulp.

HUDSON RIVER SYSTEM.

Hudson River, with its principal tributary, the Mohawk, is the most important river of the State. From its mouth to Troy, a distance of over 150 miles, it is a great inland estuary subject to tidal action, and because of its great length and the large fresh-water inflow it is unique among inland estuaries. From the first landing of the Dutch on Manhattan Island to the present time it has been an important channel of commerce. On his voyage of discovery in 1609, Hendrik Hudson ascended to the head of tide water, and doubtless discerned the possibilities of future settlement which were so soon realized at Albany, Waterford, and Schenectady. The tidal action of Hudson River originally terminated at the rapids above Troy, but its present termination is a few miles below, at the Troy dam, a structure erected about 1820 as a part of the State canal system. There is a lock at the east end of this dam through which canal boats pass into the pool above, thus enabling them to reach Lansingburg on the east side of the river, or Waterford on the west side, where they may enter Champlain Canal.

Below Troy the tributaries of Hudson River are mostly small and generally not of very great importance, although some of them have considerable power development. One of them, Croton River, is the principal source of water supply of the city of New York. On this part of the river the drainage basin is rather narrow, and many of the streams issuing from the highlands at either side have such small drainage areas as to carry only moderate quantities of water. In descending the river from Troy the principal streams are, on the west side, Normankill, Catskill, Esopus, and Rondout creeks, and on the east side Kinderhook, Wappinger, and Fishkill creeks and Croton River. Harlem River, connecting the Hudson with East River, may be mentioned, in view of its value to navigation interests, as an important feature of the water resources of New York.

The following are the elevations of mean tide, mean low tide, and mean high tide above mean sea level at New York, and the mean rise

and fall of tides at various points along the tidal estuary between New York Bay and the Troy dam:

Mean tidal elevations in feet at various points between New York Bay and Troy dam.

Locality.	Mean tide.	Mean low tide	Mean high tide.	Mean rise and fall.
Sandy Hook				4.70
Governors Island	0.00	2.20	2.20	4.40
Dobbs Ferry	0.18	1.62	1.98	3.60
Coxsackie light-house	1.68	0.17	3.53	3.70
New Baltimore	1.73	0.02	3.44	3.42
Colymans	1.88	0.44	3.31	2.87
Castleton	2.09	0.82	3.35	2.53
Van Wies	2.13	0.82	3.29	2.33
Albany	2.43	1.27	3.59	2.32
Nail works	2.78	1.81	3.75	1.94
Troy dam	3.77	3.37	4.17	0.80

The most important tributaries begin above Troy. Ascending on the west side we find Mohawk River, the outlet of Saratoga Lake, Sacundaga River, Stony and North creeks, and Indian and Cedar rivers. On the east side there are Hoosic, Battenkill, Schroon, and Boreas rivers. Above the mouth of Cedar River the main North or Hudson River is considered to extend to and beyond Lake Sanford, including Opalescent River and the streams issuing from the high Adirondacks.

The following gives the height above tide water at New York of a number of points on Hudson River.

Height above tide water at New York of points on Hudson River.

	Feet.
New York (at mouth)	0.0
Troy	3.8
Saratoga dam (crest)	102.0
Fort Edward (below dam)	118.0
Glens Falls (crest of feeder dam)	284.0
Mouth of Sacundaga River	556.0
Mouth of Stony Creek	584.0
Mouth of Schroon River	608.0
At Glen Bridge	728.0
At Riverside Bridge	875.0
At North Creek Bridge	998.0
At North River	1,050.0
Mouth of Boreas River	1,140.0
Mouth of Indian River	1,415.0
Mouth of Cedar River	1,460.0
Lake Sanford	1,723.0

MOHAWK RIVER.

Mohawk River, the most important tributary of the Hudson, rises in the western-central part of the State, near the Lewis and Oneida county line. It flows in a southerly direction to the city of Rome, from which it takes an easterly course across the State, emptying into the Hudson a little above Troy. The principal tributaries are Schoharie, East Canada, West Canada, and Oriskany creeks.

The following are the elevations above tide water of a number of points along Mohawk River:

Elevations of points along Mohawk River.

	Feet.
At mouth	12
Lower Mohawk Aqueduct	162
Schenectady	214
Mouth of Schoharie Creek	270
At Rome, above feeder dam	431

There are two principal falls of Mohawk River, the Great Falls at Cohoes and the Little Falls at the city of the same name, where are found the only important water powers thus far developed on this stream. At Cohoes are the Great Falls, about 120 feet in height, on which the Cohoes Company has developed about 105 feet. At Little Falls there is a total fall of about 45 feet occurring in a little over half a mile. Of this, from 38 to 40 feet are utilized by three dams. Aside from a small amount of power developed below Cohoes, just above the "sprouts" of the Mohawk, there are no water-power developments on the stream other than those of Cohoes and Little Falls, except a few unimportant mills on the extreme head waters. The waterworks of the city of Rome, at Ridge Mills, 2 miles north of Rome, where a water-power pumping system is in use, may, however, be mentioned.

The following are the principal subdivisions of the drainage areas of Mohawk River:

Subdivisions of drainage area of Mohawk River.

	Sq. miles.
At mouth	3,400
Below mouth of Schoharie Creek	3,100
At Little Falls	1,275
At Utica	524
At Rome	184

SCHOHARIE CREEK.

Schoharie Creek rises in the southern part of Greene County, whence it flows 18 miles northwesterly and then northerly about 50 miles to the Mohawk. The principal subdivisions of the drainage area are as follows:

Subdivisions of drainage area of Schoharie Creek.

	Sq. miles.
At mouth	947
Central Bridge	684
Gilboa	308

The drainage area of Schoharie Creek comprises the greater part of Schoharie County and portions of Greene, Albany, Delaware, Otsego, Montgomery, and Schenectady counties. Its head waters drain the western and northern slopes of the Catskill Mountains. At Central Bridge, about 19 miles from the mouth of the creek, the water surface is 560 feet above tide water; at the mouth the elevation is 274 feet. In spite of this large fall Schoharie Creek is not considered especially valuable for water-power development. It is subject to great extremes of flood and low-water flow. This is probably explainable by the nearly complete cutting off of the forests from the drainage area many years ago. The water powers thus far developed in the Schoharie Creek Basin are nearly all small and unimportant.

EAST CANADA CREEK.

The second important tributary of the Mohawk is East Canada Creek, which rises in the southwestern part of Hamilton County and flows southerly, joining the Mohawk at East Creek, about 7 miles from Little Falls. According to a map furnished by Stephen E. Babcock, of Little Falls, the total drainage area of East Canada Creek is 285.7 square miles, of which 58.2 square miles are in Hamilton County, 98.4 square miles in Herkimer County, 128 square miles in Fulton County, and 1.1 square miles in Montgomery County. Following are the elevations of principal points on East Canada Creek:

Elevations of principal points on East Canada Creek.

	Feet.
Bottom of Beardslee Falls near mouth	0
Top of Beardslee Falls	105
Bottom of High Falls	327
Top of High Falls	379
Crest of dam at Dolgeville	445
Mouth of Spruce Creek	477
Mouth of Fish Creek	559
Emmonsburg	646
Stratford	720
Oregon	1,140

The distance from the mouth of the stream to Oregon is about 25 miles.

The principal tributary of East Canada Creek is Fish Creek, which is the outlet of the East Canada lakes. The distance from its point of junction with East Canada Creek to the mouth of the Canada lakes outlet is about 9 miles, and the total rise in this distance 635 feet. The outlet of the lakes, which is nearly level, is about 3.5 miles long. There are no falls of any magnitude on this creek. For the first 5 miles from its mouth Fish Creek rises 245 feet, and from that point to the mouth of the outlet of the East Canada lakes, a distance of 4 miles, the rise is 390 feet.

The second tributary of East Canada Creek is Spruce Creek, which has a total length from its mouth to its head in the Eaton Millpond of about 8.7 miles, the total rise in this distance being about 550 feet. Just below the Eaton Millpond there is a fall of 180 feet in 2,000 feet. At Salisbury Center, Spruce Creek falls 85 feet in about 900 feet. Aside from the development at Dolgeville, and small developments at Beardslee Falls and at one or two other points, very little use has thus far been made of the water power of East Canada Creek. It is probable, however, that within a few years the water power of this stream will be nearly all utilized.

According to a manuscript report on the water power of East Canada Creek, by S. E. Babcock, the fall in this stream for the first 1,500 feet from its junction with Mohawk River is very slight. At this point the first rapids are encountered, where it has been proposed to develop a water power, with a head of about 60 to 70 feet. About 1,000 to 1,200 feet farther upstream there is an additional fall of from 30 to 40 feet. This takes us to the top of the so-called Beardslee Falls, referred to above.

It has also been proposed to construct an extensive system of power development by a series of dams on East Canada Creek, some of the details of which may be gathered from the following table:

Plan of power development on East Canada Creek.

Location.	Head (in feet).	Horse-power.	Estimated cost.	Cost per horse-power.
Twin Bridges	43	1,172	$108,427	$92.51
Green street	26	1,023	73,667	72.01
Factory	29	1,141	30,910	27.10
Intermediate	22	865	46,090	53.28
High Falls	72	2,700	56,320	20.86
No. 1 (below High Falls)	74	2,956	125,092	42.40
No. 2 (below High Falls)	34	1,360	56,408	41.40
No. 1 (Ingham's mill)	44	1,778	135,410	76.16
No. 2 (Ingham's mill)	44	1,778	129,800	73.00
Beardslee Falls	105	5,112	128,326	25.10
Totals and mean	423	19,885	890,450	44.80

This plan of power development further includes the construction of a storage of 1,250,000,000 cubic feet, which is estimated to cost $148,000, making a total for the whole development of $1,038,450. With these figures the final cost per net horsepower becomes $52.22. The estimates leading to this result include cost of land to be flooded, masonry of dams and head works, turbine water wheels, flumes and head feeders, tail raceways, waste gates, power stations, racks, engineering

and superintendence, etc. So far as the actual power developments are concerned, the work can probably be constructed for the estimates, but the cost of the storage is, in the author's opinion, somewhat too low. The total number of dams which it is proposed to build is stated at 40, thus giving an average of only $3,700 per dam. This sum would only build timber dams of the most temporary character. The proper operation and repairs of this number of dams, scattered over an area of 200 square miles, would entail in the end an annual expense of $30,000, which is the annual interest at 5 per cent on $600,000. To obtain the real capitalized cost we need then to add $600,000, which gives an amended total of $1,638,450, whence the cost per net horsepower for the entire system would become $82.40.

At present an electric-power station is in process of installation by the Dolgeville Electric Light and Power Company at the high falls just below Dolgeville, shown on Pl. VI, by which it is expected to develop 1,200 net horsepower. The wheels to be set are two twin horizontal 36-inch Victor special wheels, to work under a 72-foot head, and which are claimed by the manufacturers to yield, at full capacity, 600 net horsepower each. A portion of the power generated at this station is to be used at Dolgeville for manufacturing, and the balance, it is stated, will be transmitted to Little Falls, 8 miles distant.

Dolgeville is the seat of the piano-felt and other industries established by Alfred Dolge & Son. The power for the establishments now in operation is derived from two 35-inch Victor turbines, working under a 25-foot head, and rated by the manufacturers to furnish, when running at full capacity, 229 net horsepower each, or a total of 458 horsepower. According to the manufacturer's catalogue, these wheels will consume 197 cubic feet per second when working at full capacity, and the statement is made that they are ordinarily so worked. The drainage area of East Canada Creek above Dolgeville is about 250 square miles; hence the present development is based upon a minimum flow of 0.79 cubic foot per second per square mile. As there is very little pondage at Dolgeville, it may be assumed that the power is sometimes short in a dry season, although the effect of the pondage of the large number of lakes and ponds on the head waters of East Canada Creek will undoubtedly be to increase considerably the minimum flow.

WEST CANADA CREEK.

West Canada Creek, the third important tributary of the Mohawk, rises near the center of Hamilton County and flows southwesterly about 40 miles, by general course, to the eastern edge of the town of Trenton, in Oneida County, where it turns and first runs southeasterly and then southerly for a total distance of 20 miles, finally empty-

A. DAM AT HIGH FALLS OF EAST CANADA CREEK.

B HIGH FALLS AT TRENTON, ON WEST CANADA CREEK.

ing into the Mohawk at the village of Herkimer. The total drainage area above Herkimer is given as 548 square miles. This creek has its source in the Canada lakes, which are about 40 miles northeast from the village of Prospect. These lakes are known separately as the West, Middle, and East Canada. The principal lake of this series has an elevation of 2,348 feet above tide water. The drainage area at the village of Prospect, where there is a natural fall of about 22 feet, is 375 square miles. At Trenton Falls, 3 miles below, the stream descends about 200 feet in half a mile. Ascending the stream, the principal falls, in order, are: Sherman Falls, 24 feet; High Falls (shown in Pl. VI), 105 feet; Mill Dam Falls, 14 feet; Suydam Falls, 12 feet.

According to a report made by Wallace C. Johnson, under date of March 17, 1896, to the Trenton Falls Power Company, it appears that of the 375 square miles of drainage area above Prospect about 175 square miles lie at an elevation of between 2,000 and 3,000 feet above tide water, the average elevation of this portion being about 2,500 feet. Of the remaining 200 square miles above Prospect the average elevation is placed at not less than 1,600 feet. The Trenton Falls Power Company is reported as intending to develop an extensive storage on the head waters of this stream, thus enabling it to produce several thousand electrical horsepower at Trenton Falls for transmission to Utica, Rome, and other towns in the vicinity. General plans have been prepared by Mr. Johnson, but the details of the project are not at hand. Judging from the data at hand, the author is disposed to place the minimum flow of West Canada Creek at from 0.30 to 0.35 of a cubic foot per square mile per second.

Water powers are now in use on West Canada Creek at Herkimer, Middleville, Newport, and Prospect, as well as at a few points higher up.

Parties interested in the development of an extensive power project at Trenton Falls have claimed that a very large storage reservoir could be constructed in the main valley of West Canada Creek a short distance above Prospect, and at very low cost per unit volume stored. The data are not at hand for accurately determining the cost of a reservoir at this place. However, casual inspection of the Remsen sheet of the topographic map of the State, made in 1897, shows that such a reservoir would probably be expensive in proportion to the storage gained. A trial estimate shows that with a dam from 80 to 100 feet in height a storage of about 2,000,000,000 cubic feet may be obtained. The cost of the dam necessary to store this quantity of water can hardly be placed as an experimental figure at less than $1,000,000, whence the cost per 1,000,000 cubic feet stored would become $500. This approximate estimate has no other significance than to indicate the importance of studying large reservoir projects in detail before deciding as to their feasibility.

OTHER TRIBUTARIES OF MOHAWK RIVER.

As less important tributaries of the Mohawk, Sauquoit and Oriskany creeks may be mentioned. Sauquoit Creek rises in the southeastern part of Oneida County and runs northerly, emptying into the Mohawk about 2 miles west of Utica. Its drainage area is given as 62 square miles. Oriskany Creek rises in the eastern-southerly portion of Madison County and flows northerly into the Mohawk 6 miles west of Utica. Its drainage area is given as 135 square miles. There is considerable water power developed on both Sauquoit and Oriskany creeks.

HOOSIC RIVER.

The most important tributary of the Hudson from the east is Hoosic River, which rises in the mountains of Berkshire County, Massachusetts. It first runs northwesterly, passing from Massachusetts into the extreme southwestern corner of Vermont and thence into Rensselaer County, in New York. At the northern boundary of Rensselaer County it turns and pursues a westerly course to the Hudson opposite the village of Stillwater. Its drainage area at the mouth is taken at 730 square miles. Its principal tributaries are Little Hoosic River, Walloomsac River, and Tomhannock Creek. The country drained is mainly mountainous, the summits attaining an elevation of from 1,000 to 2,000 feet above tide. The principal water powers developed on Hoosic River, in New York, are at Schaghticoke and Hoosic Falls, with a few at intermediate points. At Schaghticoke there is from 97 to 98 feet fall, broken into falls of 8, 7.5, 24.5, 34.5, and 23 feet. The available statements as to the power at Hoosic Falls are so conflicting that it is thought best to omit them.

Hoosic River is of considerable interest to persons concerned in water-power development on the Hudson below its mouth, because there are two reservoirs on its headwaters which have been constructed by manufacturers in Massachusetts in order to maintain a more equable summer flow. The first of these is the Clarksburg reservoir, on the North Branch of Hoosic River, and at a distance of about $2\frac{1}{2}$ miles above North Adams. The second reservoir is on the South Branch, and is known as the Cheshire reservoir, being situated in the town of that name. The Clarksburg reservoir is stated to flow 156 acres and to have a depth of 22 feet. The Cheshire reservoir flows about 650 acres and can be drawn down about 8 feet. Both these reservoirs are controlled by an association of mill owners on the Hoosic and its branches in the State of Massachusetts.

BATTENKILL RIVER.

Battenkill River, another important tributary of the Hudson, rises in the southwestern part of Vermont, in Bennington County. It first

BIG FALLS OF BATTENKILL RIVER.

flows southwesterly and then westerly irregularly across Washington County, New York, to the Hudson at a point about a mile above Schuylerville. The drainage area is taken at 460 square miles. The elevation above tide at the mouth of the river is 82 feet, and at the Delaware and Hudson Railway crossing, a little south of Shushan, the elevation is 437 feet. This gives a descent of 355 feet in 22 miles, about one-half of which is concentrated within the last 4 or 5 miles of the river's course.

The following is a brief statement of the water powers on the lower section of the Battenkill, in ascending order from the mouth:

Water powers on the lower section of the Battenkill.

At Clark Mills, the American Woodboard Company, 24 feet head.

At Big Falls (shown on Pl. VII), the dam at the head of the falls gives 106 feet head, divided into Bennington Falls Pulp Company, 32 feet; Ondawa Pulp and Paper Company, 30 feet; not utilized, 44 feet.

At Middle Falls, the dam at the head of the falls gives 55 feet head. Here there are a leather-board mill, shank mill, sawmill, plaster mill, gristmill, and electric-light station.

At Greenwich, Dunbar, McMaster & Co., 8 feet head; Palmer's lower dam, 9 feet head, furnishes power for gristmill, paint works, shirt manufacturing, scale manufacturing, and plow works; Palmer's upper dam, 6 feet head, furnishes power for a cotton mill and a paper mill.

At Center Falls, Angel & Langdon Paper Mill, 25 feet head.

At Battenville, Phœnix Paper Company, 10 feet head.

At Rexleigh there is a cotton mill with 6 feet head; at Shushan a gristmill, shirt factory, electric-light station, and foundry, all receiving power from about 14 feet head.

In addition to the foregoing there are stated to be undeveloped water powers on the Battenkill as follows: Between Clark Mills and Big Falls, 27 feet; between Greenwich and Center Falls, 8 feet; between Center Falls and Battenkill, 10 feet.

It is stated that the utilized powers on the Battenkill are developed up to about 30 horsepower per foot fall. They are, however, sometimes short of water in dry weather. With a drainage area of 460 square miles, a minimum flow of 0.3 of a cubic foot per square mile per second would give only about 15.3 gross horsepower per foot of fall. It is inferred, therefore, that the Battenkill is an exceedingly good water yielder, although definite data derived from stream measurements are entirely lacking.

FISH CREEK.

Fish Creek, a stream tributary to the Hudson at Schuylerville, is the outlet of Saratoga Lake. Its chief tributary is the Kayaderosseras Creek, which drains the central part of Saratoga County. The drainage area of Fish Creek at its junction with the Hudson is estimated at 253 square miles. Both Fish Creek and Kayaderosseras Creek are extensively utilized for water power.

SACUNDAGA RIVER.

Sacundaga River, a view of which is given on Pl. VIII, is the next important tributary of the Hudson in the ascending order. It has three principal branches, which unite to form the main river in the southeastern part of Hamilton County. The West Branch is the outlet of Piseco Lake; the Middle Branch is the outlet of Sacundaga and Pleasant lakes, while the East Branch issues from a series of small ponds and lakes in the southwestern part of Warren County, not far from Bakers Mills. The East and Middle branches unite a few miles to the north of Wellstown, and West Branch joins a few miles south of Wellstown. The river then flows southeasterly to about 5 miles below Northville, where it turns rather more than a right angle and flows irregularly northeast to the main Hudson at Hadley. The principal tributary of the Sacundaga, aside from its several branches, is East Stony Creek.

The following are the several subdivisions of the drainage area of Sacundaga River:

Subdivisions of the drainage area of Sacundaga River.

	Sq. miles.
Total drainage area at mouth	1,040
South Branch	240
Middle Branch	115
East Branch	124
Stony Creek	212
Main river below Stony Creek	223

The following are elevations above tide at a number of principal points:

Elevations above tide of points along Sacundaga River.

	Feet.
At mouth of river	556
Above dam at Conklinville	697
Northville	732
Hope Center	763
Wellstown	902
East Branch at old tannery	958
East Branch at foot of High Falls	1,205
East Branch at head of High Falls	1,337
East Branch at Brighams Pond	1,706
Piseco Lake	1,648
Lake Pleasant	1,706
Sacundaga Lake	1,706

From Conklinville to the mouth of the river, a distance of a little over 5 miles, the river falls 141 feet. At present this section of the river is entirely unutilized except by two powers, one at Conklinville and the other about 2 miles from Hadley.

Thus far there are no detailed measurements of the Sacundaga, but since the drainage area is still largely in primeval forest it is without doubt an excellent water yielder.

A. HUDSON RIVER ABOVE LUZERNE

B. SACUNDAGA RIVER NEAR LUZERNE.

SCHROON RIVER.

Schroon River rises in Essex County, along the southern slopes of the highest mountains of the Adirondack group. As shown by the map (Pl. IX), it flows in a general southerly direction for about 45 miles, through Essex and Warren counties, and joins the Hudson just above Thurman. On the boundary between Essex and Warren counties the river flows through Schroon Lake, a body of water nearly 9 miles long and from a little less than 0.5 to 1.5 miles in width.

The following are some of the important subdivisions of the drainage area of Schroon River:

Subdivisions of the drainage area of Schroon River.

	Square miles
At mouth	550
Warrensburg	535
Tumblehead Falls	502
Foot of Schroon Lake	479

Some of the elevations on Schroon River are as follows:

Elevations on Schroon River.

	Feet.
At mouth	610
Schroon Lake	807
Paradox Lake	820
Schroon Falls	840
Elk Lake	1,986

There is no developed water power on Schroon River except that at Warrensburg.

TRIBUTARIES SOUTH OF MOHAWK RIVER.

Kinderhook Creek and Croton River are the chief tributaries of the Hudson south of the Mohawk requiring special mention at this time. Brief consideration of the run-off of Croton River will be given further on. The Columbia Electric Light Power Company, of Valatie, was incorporated by the laws of 1897 to construct reservoirs and create extensive power developments on Kinderhook Creek and its tributaries in Columbia and Rensselaer counties. The surveys for this work are now in process under the direction of L. L. Tribus, chief engineer of the company.

Wallkill River, a branch of Rondout Creek, may be mentioned. This stream rises in New Jersey and flows north, joining Rondout Creek near Rondout. It is proposed to take an additional water supply for Brooklyn Borough of Greater New York from the head waters of this stream in New Jersey. The drainage area south of the New York State line is 210 square miles.

ALLEGHENY RIVER SYSTEM.

The Allegheny River enters the State of New York from Pennsylvania in the southeastern corner of Cattaraugus County and, flowing in nearly a semicircle with its outward curve to the north, passes out of the State in the southwestern part of Cattaraugus County, again entering Pennsylvania. Its principal tributary from the north is Conewango Creek, which receives the outlet of Chautauqua Lake and of Cassadaga Creek as tributaries. Little Valley, Great Valley, and Olean creeks are also tributaries in New York. None of these streams is of especial importance for water power.

Chautauqua Lake, 20 miles in length and from 1 to nearly 2 miles in width, is distant from Lake Erie at its northern extremity only about 9.5 miles. Its elevation above tide water is 1,297 feet, while that of Lake Erie is 573 feet. Hence Chautauqua Lake is 724 feet above Lake Erie. The Conewango Creek, at the south line of the State, has an elevation of 1,243 feet. The fall from Chautauqua Lake to the southern boundary of the State along the drainage line is therefore only 54 feet. The drainage area of the Chautauqua outlet at the foot of Chautauqua Lake is 178 square miles, and of the Chautauqua outlet below Cassadaga Creek 343 square miles.

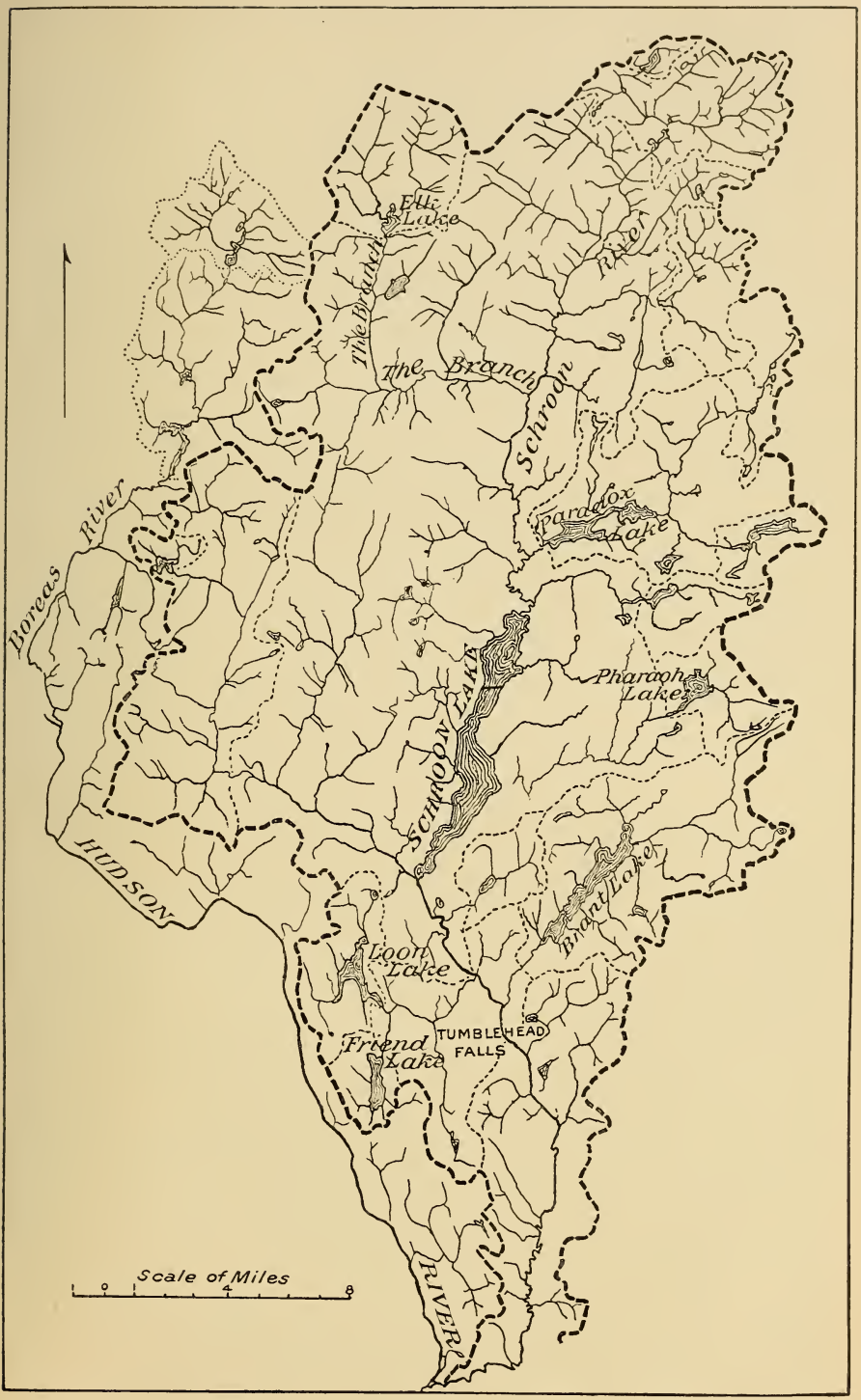
SUSQUEHANNA RIVER SYSTEM.

The head waters of the North Branch of Susquehanna River lie chiefly in the State of New York, the drainage area in this State being taken at 6,267 square miles. The main stream is considered as rising in Otsego Lake, from which it flows first southwesterly, then westerly with a short portion of its course south of the Pennsylvania line. It finally leaves New York State in Tioga County. The Susquehanna, while one of the large rivers of New York, is not at all important as regards water power. The main river and most of its tributaries in New York flow through a rolling country with fairly uniform declivity. While utilized for small powers in many places, thus far there are no extensive developments on either the main stream or its branches, except at Binghamton, where considerable water power is utilized. The slope of the stream in New York State is shown by following elevations, in feet, above tide water:

Elevations along Susquehanna River in New York State.

	Feet.
At Towanda, a few miles south of the State line	700
At Athens, on Chemung River, near the State line	744
At Otsego Lake	1,193

So far as known, no discharge measurements of this stream have ever been made.



DRAINAGE AREA OF SCHROON RIVER.

As one of the important tributaries of the North Branch of Susquehanna River in New York may be mentioned Chenango River, which rises in Madison County, and flows south through Madison, Chenango, and Broome counties, emptying into the Susquehanna at Binghamton. Chemung River, the chief tributary of the North Branch, is formed in Steuben County, New York, near Painted Post, by the junction of the Tioga and Cohocton Rivers, whence it pursues a southeasterly course, joining the Susquehanna near Athens, in Bradford County, Pennsylvania, just south of the State line. Tioga River rises in Tioga County, Pennsylvania, and flows north to join the Cohocton at Painted Post. Canisteo, the principal New York State tributary of the Tioga, joins the main stream 5 miles south of Painted Post. Cohocton River, which rises in Livingston County, and flows southeast to join the Tioga at Painted Post, is utilized for small powers at a number of places. The area drained by the Cohocton and Canisteo is almost entirely denuded of forest and the streams are in consequence much less valuable for power than formerly. For a considerable length of time, in the fall of 1895, the natural yield of these streams was probably considerably less than one-tenth of a cubic foot per second per square mile.

Other tributaries of the Susquehanna in New York State are Owego and Cuyuta creeks, neither of which, although formerly extensively utilized for small powers, is now of great value, largely because of the exceedingly slight summer flows.

The following are the drainage areas of the Susquehanna and its tributaries in the State of New York:

Drainage areas of Susquehanna River and its tributaries in New York.

	Square miles.
Main river below mouth of Chemung River (south of Pennsylvania line)	7,463
Total area north of Pennsylvania line	6,267
Above mouth of Chemung River	4,945
At Binghamton	2,279
At Susquehanna	2,024
At Nineveh	1,789
Below mouth of Unadilla River	1,638
Below mouth of Oak Creek	212
Above mouth of Oak Creek	97
Oak Creek	115
Cherry Valley Creek	121
Chenevas Creek	127
Charlotte River	178
Otego Creek	106
Oaliout Creek	115
Unadilla River	561
Butternut Creek	123
Chenango River at mouth	1,540
Chenango River above Tioughnioga	685
Chenango River above Canasawacta Creek	297
Tioughnioga River at mouth	735

Drainage areas of Susquehanna River and its tributaries in New York—Cont'd.

	Square miles.
Tioughnioga River above mouth of Otselic River	428
Otselic River	259
West Branch of Tioughnioga River	103
East Branch of Tioughnioga River	164
Owego Creek	391
Cayuta Creek	148
Chemung River at junction of Canisteo and Cohocton rivers	1,941
Chemung River at Elmira	2,055
Chemung River at mouth	2,518
Cohocton River at mouth	425
Tioga River at mouth	1,530
Tioga above mouth of Canisteo	750
Canisteo at mouth	780
Tuscarora Creek at mouth	120

DELAWARE RIVER SYSTEM.

The extreme head waters of Delaware River, in New York, are a series of small ponds in Schoharie County, a little north of the village of Stamford. From this point the stream flows southwesterly to Deposit, on the line between Broome and Delaware counties, where it turns south, on which general course it continues until near the Pennsylvania line, whence its course is southwesterly to Port Jervis. This portion of the river is the boundary line between New York and Pennsylvania. At Port Jervis the river passes from New York State, making a sharp turn to the southwest. The declivity of Delaware River is shown by the following elevations above tide water:

Elevations along Delaware River in New York State, showing declivity of the stream.

	Feet.
At Lackawaxen	600
At Deposit	984
At head waters	1,886

The principal tributary in New York State is Pepacton River, which rises in the eastern part of Delaware and Greene counties and flows southwest in a course generally parallel to the main stream. Neversink Creek, the next important tributary in the State, joins the main stream at the State line a mile south of Port Jervis. Neither of these streams has thus far developed any large amount of water power, although there are a number of places where good powers could be developed. The cutting off of the forests of the Delaware drainage area has undoubtedly greatly injured the tributary streams for mill purposes.

The following are the more important drainage areas on the Delaware and its tributaries in New York State:

Drainage areas on Delaware River and tributaries in New York State.

	Square miles.
Total area in New York State	2,580
Main stream below mouth of Neversink River	3,600
Main stream below Port Jervis	3,252
Main stream below junction of East and West branches	1,604
West Branch at mouth	685
West Branch at Deposit, below Oquaga Creek	519
Pepacton River at mouth	919
Above mouth of Beaverkill	520
Beaverkill Creek	322
Oquaga Creek	82
Little Delaware Creek	53
Neversink River at mouth	346

By way of concluding the general discussion of the Allegheny, Susquehanna, and Delaware river systems in the State of New York, it may be remarked that these have all been extensively used, either for floating logs or for propelling sawmills, or for both. The clearing up of the drainage areas has, however, long since reduced the lumbering business to nothing. These streams are, therefore, much less extensively utilized than formerly. At present, aside from one or two points, their use is chiefly for propelling small sawmills and gristmills and for other moderate-sized industries. With one or two exceptions, there are no large power developments throughout the whole region.

STREAMS OF LONG ISLAND.

Long Island is chiefly a sandy plain, about 120 miles in length, with a total area of 1,682 square miles. A considerable portion is below an elevation of 100 feet above tide water, although in places it rises to elevations of 300 feet and more. The streams are all small and only a few miles in length, running down from the high land of the middle section to the Atlantic Ocean on the south and to Long Island Sound on the north. As regards water power, the water resources of Long Island have little significance, although there are many places where small powers are utilized for gristmills and other similar uses. The chief value of the inland water of Long Island is for the water supply of the city of Brooklyn.

East River, which connects Long Island Sound with New York Bay, may also be referred to for convenience as a Long Island water resource. The great value of the stream to the commerce of New York is so obvious as to hardly require mention.

The foregoing description of the river systems of New York has

been made as brief as possible, because very complete descriptions have been given in the several monographs relating to New York State which appear in the report on the Water Power of the United States, Tenth Census, 1880. In these reports may be found full details of the several river valleys, with statements as to agricultural production, population, geology, climatology, and many other subjects not touched on here.

AVAILABLE WATER SUPPLY.

RUN-OFF OF NIAGARA RIVER.

The great developments of the Niagara Falls Power Company, authorized by the laws of 1886, have been in part completed, while at the same time the original Niagara Falls power development, now owned by the Niagara Falls Power and Manufacturing Company, has increased greatly in capacity. The laws of 1886, and amendments thereto, have also authorized the taking from Niagara River of large quantities of water for the purpose of creating a water power near the city of Lockport. A ship canal is projected connecting Lakes Erie and Ontario, and the Canadian Government has made a concession for extensive power developments on the Canadian side of the river. Hence it is evident that the future demands for water to be taken from Niagara River and delivered either into the lower river below the Falls or into Lake Ontario independent of the river are very large, and the interest which the people of the State of New York have in the run-off of Niagara River becomes exceedingly important.

The most recent determination of the area of the basin drained by the Great Lakes and of the water surfaces of the lakes themselves is that given in the report of the United States Deep Waterways Commission, from which the following general summary is taken:

Water surface and watershed areas of the basin drained by the Great Lakes.

Lake.	Area of water surface.	Area of watershed.	Total area of basin.
	Square miles.	*Square miles.*	*Square miles.*
Superior	31,800	48,600	80,400
Michigan	22,400	45,700	68,100
Huron	23,200	52,100	75,300
St. Clair	495	6,320	6,815
Erie	10,000	24,480	34,480
Total	87,895	177,200	265,095

That portion of the drainage area of Lake Erie lying within the State of New York is given as 2,210 square miles. The area of islands in Niagara River is given as 29 square miles. That portion of the watershed of Niagara River lying within the State of New York has an area of 789 square miles. The area of the river itself, from its head at Lake Erie to the Falls, is 21 square miles.[1]

The accompanying table gives the precipitation within and in the vicinity of the drainage area of the Great Lakes for the years from 1892 to 1895, inclusive. In this table a few only of the many precipitation records which are now available have been used. The records there appearing are, it is believed, sufficient to show the mean precipitation of the basin of the Great Lakes for the years indicated. In this and subsequent tables the water year[2] is considered as beginning with the month of December of the preceding year. Thus the water year of 1879 extends from December, 1878, to November, 1879, inclusive. The months from December to May constitute what may be termed the storage period. During this time vegetation is inert, the temperature low, with consequent light evaporation. Usually from 70 to 80 per cent of the precipitation of this period runs off in the streams.

June to August, inclusive, is the growing period. Then the temperature is at its highest for the year and vegetation is active. For this period only about 20 per cent of the rainfall appears in the streams, and some of that is usually the stored ground water of the preceding period.

September to November, inclusive, is the replenishing period. The temperature is again relatively low, vegetation inert, and the rainfall goes to replenish the stock of ground water, depleted during the growing period, or, after the ground again becomes full, appears as direct run-off in the streams. In the table the monthly precipitation has been omitted, as it can readily be found in the annual reports of the United States Weather Bureau, and the data have been condensed to show the total quantities for the storage, growing, and replenishing periods, together with the total annual amounts.

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[1] Report of the United States Deep Waterways Commission, by the commissioners, James B. Angell, John E. Russell, Lyman E. Cooley. Accompanied by the report on technical work and the several topical reports and drawings pertaining thereto. Printed as House Document No. 192, Fifty-fifth Congress, second session, Washington, 1897, pp. 146, 147.

For the drainage area of the Great Lakes in detail reference may be made to an excellent map of the basin of the Great Lakes and of St. Lawrence and Hudson rivers in relation to the surrounding drainage systems accompanying the report of the Deep Waterways Commission.

[2] Report of the State Engineer and Surveyor of New York, 1895, p. 99.

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Pokegama Falls, Minn.:				
1892	11.76	6.99	2.86	21.61
1893	9.64	13.06	2.84	25.54
1894	14.72	8.04	9.01	31.77
1895	9.14	12.49	5.70	27.33
Mean				*26.56*
Duluth, Minn.:				
1892	17.96	11.78	2.39	32.13
1893	11.08	6.86	3.64	21.58
1894	19.44	3.80	8.51	31.75
1895	6.44	9.32	7.70	23.46
Mean				*27.23*
Minneapolis, Minn.:				
1892	13.78	23.32	2.33	39.43
1893	12.80	9.79	5.68	28.27
1894	15.66	1.73	6.46	23.85
1895	7.72	9.96	5.01	22.69
Mean				*28.56*
Green Bay, Wis.:				
1892	14.95	12.47	7.95	35.37
1893	14.85	8.12	7.15	30.12
1894	19.65	8.52	10.46	38.63
1895	10.06	7.52	3.14	20.72
Mean				*31.21*
Madison, Wis.:				
1892	18.89	13.34	4.89	37.12
1893	13.37	12.75	5.82	31.94
1894	10.96	6.23	7.61	24.80
1895	5.54	3.88	2.57	11.99
Mean				*26.46*
Milwaukee, Wis.:				
1892	18.17	11.00	5.71	34.88
1893	15.69	10.14	6.06	31.89
1894	15.94	4.81	8.79	29.54
1895	10.34	7.45	5.33	23.12
Mean				*29.86*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Chicago, Ill.:				
1892	16.03	14.66	5.56	36.25
1893	13.93	6.85	6.18	26.96
1894	14.48	3.16	10.30	27.94
1895	9.58	10.70	7.00	27.28
Mean				*26.61*
Logansport, Ind.:				
1892	27.26	10.91	6.97	45.14
1893	24.45	4.52	8.92	37.89
1894	21.11	4.58	7.82	33.51
1895	9.08	6.40	8.56	24.04
Mean				*35.15*
Ann Arbor, Mich.:				
1892	14.52	8.18	7.70	30.38
1893	20.54	7.18	10.33	38.05
1894	16.63	2.76	7.21	26.60
1895	8.92	5.40	4.70	19.02
Mean				*28.51*
Grand Haven, Mich.:				
1892	16.57	8.93	4.97	30.47
1893	19.02	6.79	8.68	34.49
1894	19.84	4.07	11.08	34.99
1895	10.89	4.88	6.17	21.94
Mean				*30.47*
Marquette, Mich.:				
1892	16.03	3.53	8.89	28.45
1893	14.81	9.16	7.41	31.38
1894	24.65	5.25	9.31	39.21
1895	16.35	7.04	8.89	32.28
Mean				*32.83*
St. Ignace, Mich.:				
1892	12.39	10.30	6.43	29.12
1893	15.61	7.94	8.31	31.86
1894	17.80	6.83	9.80	34.43
1895	11.66	4.59	8.98	25.23
Mean				*30.16*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Traverse City, Mich.:				
1892	17.65	10.87	8.61	37.13
1893	17.88	7.07	11.41	36.36
1894	20.62	5.61	9.72	35.95
1895	16.69	4.53	7.85	29.07
Mean				*34.63*
Cleveland, Ohio:				
1892	19.84	11.91	5.90	37.65
1893	19.09	5.46	7.45	32.00
1894	15.28	5.55	7.77	28.60
1895	9.29	7.59	7.91	24.79
Mean				*30.76*
Toledo, Ohio:				
1892	17.77	12.76	6.47	37.00
1893	10.17	4.81	6.92	21.90
1894	14.93	2.78	5.23	22.94
1895	9.23	6.24	7.11	22.58
Mean				*26.10*
Buffalo, N. Y.:				
1892	22.62	16.93	8.32	47.87
1893	20.65	8.00	7.87	36.52
1894	22.47	5.82	12.50	40.79
1895	14.17	6.23	8.85	29.25
Mean				*38.61*
Rochester, N. Y.:				
1892	17.75	13.41	5.94	37.10
1893	18.05	9.36	6.02	33.43
1894	21.26	7.05	7.14	35.45
1895	16.16	6.84	7.15	30.15
Mean				*34.03*
Oswego, N. Y.:				
1892	15.22	15.33	6.82	37.37
1893	14.63	9.83	8.01	32.47
1894	19.55	6.46	11.13	37.14
1895	15.06	6.25	9.08	30.39
Mean				*34.34*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Winnipeg, Manitoba:				
1892	6.65	8.70	3.96	19.31
1893	8.25	10.81	4.35	23.41
1894	8.55	3.80	5.84	18.19
1895	8.18	6.62	2.42	17.22
Mean				*19.53*
Port Arthur, Ontario:				
1892	8.84	7.35	5.31	21.50
1893	8.48	7.39	6.50	22.37
1894	8.20	5.57	8.30	22.07
1895	8.76	7.86	6.05	22.67
Mean				*22.15*
Toronto, Ontario:				
1892	12.21	12.29	6.65	31.15
1893	18.64	9.85	7.86	36.35
1894	19.90	3.07	8.44	31.41
1895	11.93	6.24	7.76	25.93
Mean				*31.21*

These precipitation data are of special interest because the year 1895 was the culmination of a period of exceedingly low water. They show that for a period of four years the precipitation of this basin was low, and in consequence the run-off of the tributary streams must have been exceedingly small. As illustrating this proposition, we may first refer to the run-off of the Upper Mississippi,[1] where there is a reservoir system controlling a drainage area of 3,265 square miles, first operated about 1885. The rainfall of the area tributary to these reservoirs, as indicated by records kept at Leech Lake, Lake Winibigoshish, and Pokegama Falls from 1885 until the present time is, as an average, from 24 to 26 inches per year. The highest recorded yearly precipitation is 31.87 inches, at Pokegama Falls in 1894. The rainfall of the area tributary to the Upper Mississippi reservoirs is found to be quite similar to that of the region tributary to Lake Superior. Hence the run-off of this reservoir system may be considered as representing the run-off of the drainage area of Lake Superior and the northern portion of Lakes Michigan and Huron.

[1] Annual Report of Chief of Engineers U. S. Army for 1896, Part III, p. 1843; also for 1897, Part III, p. 2169.

The following gives the discharge from these reservoirs for the years 1892 to 1895, inclusive, corresponding with the years of precipitation shown in the table on pages 50 to 53:

Mean rainfall, run-off, and proportion of run-off to rainfall of the area tributary to the Upper Mississippi reservoirs.

Water year.	Mean rainfall on water shed.	Run-off of watershed.	Proportion of run-off to rainfall.
	Inches.	*Inches.*	*Per cent.*
1892	21.33	4.43	20.8
1893	25.42	3.61	14.2
1894	26.63	3.62	13.6
1895	25.11	2.79	11.1
Total	98.49	14.45	
Mean	24.62	3.61	14.7

The table shows that during the years 1892 to 1895, inclusive, the mean run-off of the Upper Mississippi watershed was only 3.61 inches on the total watershed. These figures, however, are subject to correction because the state of the reservoirs at the beginning and ending of the four-year period is not given in the report of the United States engineers, from which these data are taken. This correction, however, can not be very large, because the reservoirs are so operated as to be emptied, generally speaking, each year. In considering the run-off of these Upper Mississippi reservoirs, due consideration should be given to the fact that the water area of the reservoirs is 585 square miles, or nearly 18 per cent of the whole. For Lakes Superior, Michigan, Huron, St. Clair, and Erie we have a total water surface of 87,895 square miles, with a total drainage area, including the surface of the lakes, of 265,095 square miles. The water surface of these several lakes is, therefore, about 33 per cent of the entire area of the basin, or nearly double the relative area of water surface and drainage area for the Upper Mississippi reservoirs. With other conditions the same, this fact would probably lead to a somewhat greater proportion of run-off from the Great Lakes.

By way of further illustrating the yield of streams in the vicinity of the Great Lakes drainage area, we may refer to the run-off of the Des Plaines River as given in the table on page 64. This stream has been measured by the Chicago drainage commission, with certain intermissions, as shown by the table, since January, 1886, the drainage area above the point of measurement being 633 square miles. The drainage area comprises a long and narrow, flat region extending from near Chicago to a few miles north of Milwaukee, the eastern line being for the entire distance nearly parallel to Lake Michigan and in

places only 2 or 3 miles distant therefrom. The area drained by the Des Plaines River is large enough to give a fair idea of the average yield of streams tributary to Lake Michigan in northern Illinois and Indiana, western Michigan, and southern and central Wisconsin. In 1893, with a mean rainfall on the drainage area of 39.96 inches, the total run-off was 10.14 inches, of which 8.61 inches occurred during the storage period from December to May, inclusive. In 1894, with a total rainfall of 27.94 inches, the total run-off was 7.70 inches, of which 7.54 inches occurred in the storage period. For the year 1895 the total rainfall was 27.28 inches. The run-off data of this year are unfortunately incomplete, but taking into account the sequence of the rainfall it is clear that the total run-off for that year did not exceed about 2.0 to 2.5 inches. The effect of the three dry years 1893, 1894, and 1895 in the Des Plaines drainage area is shown by the record of 1896, where, with a total rainfall of 39.58 inches, the total run-off was only 6.69 inches, of which 5.39 inches occurred in the storage period. These figures indicate that the ground water of the Des Plaines area must have been so low at the end of 1895 as to absorb a large portion of the heavier rainfall of 1896 before any great amount could appear as run-off.[1]

Rainfall, run-off, evaporation, and mean temperature of Muskingum River, as measured by the United States engineers, from 1888 to 1895, inclusive.

[In inches on the watershed.]

Month.	1888.				1889.				1890.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	1.94	0.18	.....	30.8	1.50	0.84	.....	31.5	3.01	1.48	.....	41.1
January	3.96	1.24	.....	23.5	3.63	1.89	.....	31.7	4.52	3.53	.....	37.0
February	1.91	1.12	.....	29.4	1.55	1.42	.....	24.0	5.84	3.73	.....	37.5
March	4.05	1.38	.....	32.5	1.71	0.71	.....	39.0	4.38	4.23	.....	32.0
April	1.75	0.80	.....	46.9	2.23	0.88	.....	47.9	3.41	2.00	.....	48.8
May	3.55	0.45	.....	58.4	2.90	0.28	.....	59.1	6.61	3.10	.....	56.9
	17.16	*5.17*	*11.99*	*36.9*	*13.52*	*6.02*	*7.50*	*38.9*	*27.77*	*18.07*	*9.70*	*42.2*
June	2.66	0.29	.....	68.4	4.79	0.47	.....	65.7	5.27	1.64	.....	70.7
July	5.81	0.81	.....	70.4	5.35	0.55	.....	71.7	3.06	0.51	.....	70.9
August	5.84	0.67	.....	68.8	1.98	0.22	.....	67.0	5.35	0.49	.....	66.6
	14.31	*1.77*	*13.54*	*69.2*	*12.12*	*1.24*	*10.88*	*68.1*	*13.68*	*2.64*	*11.04*	*69.4*
September	3.28	0.61	.....	58.0	4.17	0.14	.....	61.3	6.86	2.28	.....	60.6
October	3.25	0.77	.....	45.6	2.35	0.14	.....	46.5	6.20	2.01	.....	51.1
November	4.61	2.01	.....	41.1	3.72	0.68	.....	40.2	2.46	1.84	.....	42.0
	11.14	*3.39*	*7.75*	*48.2*	*10.24*	*0.96*	*9.28*	*49.3*	*15.52*	*6.13*	*9.39*	*51.2*
Year	42.61	10.33	32.28	47.8	35.88	8.22	27.66	48.8	56.97	26.84	30.13	51.3

[1] For details of the measurements of the Des Plaines River see data pertaining to rainfall and stream flow, by Thomas T. Johnston, Journal Western Soc. C. E., Vol. I (June, 1896).

Rainfall, run-off, evaporation, and mean temperature of Muskingum River, as measured by the United States engineers, from 1888 to 1895, inclusive—Cont'd.

Month.	1891.				1892.				1893.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	2.45	0.91	.....	29.3	2.62	1.03	.....	37.8	1.62	0.24	.....	28.1
January	2.52	2.40	.....	31.2	2.40	0.74	.....	22.8	3.01	0.37	.....	18.0
February	4.43	4.56	.....	34.8	2.76	2.40	.....	33.0	6.38	4.70	.....	28.3
March	3.19	2.52	.....	33.5	3.10	1.26	.....	32.7	2.31	2.55	.....	36.9
April	1.74	1.58	.....	49.8	2.24	1.38	.....	46.0	5.94	2.22	.....	49.6
May	2.39	0.45	.....	55.8	7.27	2.25	.....	57.9	5.78	4.05	.....	57.0
	16.72	*12.42*	*4.30*	*39.1*	*20.39*	*9.06*	*11.33*	*38.4*	*25.04*	*14.13*	*10.91*	*36.3*
June	7.56	0.91	.....	69.0	7.05	2.30	.....	71.6	3.08	0.78	.....	70.2
July	3.92	0.51	.....	67.6	5.44	0.75	.....	70.9	2.92	0.28	.....	73.6
August	2.08	0.35	.....	68.7	4.05	0.60	.....	70.0	2.31	0.16	.....	69.5
	13.56	*1.77*	*11.79*	*68.4*	*16.54*	*3.65*	*12.89*	*70.8*	*8.31*	*1.22*	*7.09*	*71.1*
September	1.08	0.17	.....	66.5	2.33	0.28	.....	62.2	1.56	0.14	.....	63.4
October	1.25	0.26	.....	49.7	0.80	0.20	.....	50.1	5.51	0.46	.....	52.4
November	4.75	0.94	.....	38.6	1.68	0.19	.....	37.8	1.94	0.25	.....	38.4
	7.08	*1.37*	*5.71*	*51.6*	*4.81*	*0.67*	*4.14*	*50.0*	*9.01*	*0.35*	*8.16*	*51.4*
Year	37.36	15.56	21.80	49.5	41.74	13.38	28.36	49.4	42.36	16.20	26.16	48.8

Month.	1894.				1895.				Mean.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	2.59	1.54	.....	31.7	3.01	0.36	.....	33.2	.....	.....	.....	.....
January	2.11	1.00	.....	33.2	3.99	1.67	.....	22.4	.....	.....	.....	.....
February	2.95	2.19	.....	27.6	0.89	0.12	.....	19.1	.....	.....	.....	.....
March	2.20	1.41	.....	43.9	1.87	1.20	.....	33.2	.....	.....	.....	.....
April	2.45	0.75	.....	49.8	1.76	0.59	.....	50.6	.....	.....	.....	.....
May	4.63	0.74	.....	58.3	1.52	0.10	.....	60.5	.....	.....	.....	.....
	16.93	*7.63*	*9.30*	*40.7*	*13.04*	*4.04*	*9.00*	*36.5*	*18.82*	*9.57*	*9.25*	*38.6*
June	2.12	0.42	.....	70.6	2.87	0.17	.....	71.6	.....	.....	.....	.....
July	1.77	0.13	.....	73.1	2.52	0.21	.....	69.6	.....	.....	.....	.....
August	0.67	0.11	.....	70.1	3.75	0.11	.....	71.7	.....	.....	.....	.....
	4.56	*0.66*	*3.90*	*71.3*	*9.14*	*0.49*	*8.65*	*71.0*	*11.53*	*1.68*	*9.85*	*69.9*
September	4.12	0.15	.....	67.2	2.39	0.13	.....	67.2	.....	.....	.....	.....
October	2.19	0.10	.....	53.3	1.38	0.08	.....	45.3	.....	.....	.....	.....
November	2.71	0.16	.....	36.8	3.89	0.16	.....	40.8	.....	.....	.....	.....
	9.02	*0.41*	*8.61*	*52.4*	*7.66*	*0.37*	*7.29*	*51.1*	*9.31*	*1.77*	*7.54*	*50.7*
Year	30.51	8.70	21.81	51.3	29.84	4.90	24.94	48.8	39.66	13.02	26.64	49.5

In the table is given the rainfall and run-off record for Muskingum River, in Ohio, as measured at Zanesville[1] for the years 1888 to 1895, inclusive, the area of the watershed above the point of measurement being 5,828 square miles. The head waters of the stream are not far from Lake Erie and on the dividing line between the hill country of the east and the prairie country of the Mississippi Valley. Hence this stream represents conditions applicable to the run-off of the Ohio streams tributary to Lake Erie. The rainfall record as used in this table is the mean of the records kept at Akron, Canton, Newcomerstown, and Wooster, and may be considered to represent fairly well the mean precipitation of the Muskingum drainage area. For the year 1892 the total rainfall was 41.74 inches and the total run-off 13.38 inches, of which 9.06 occurred in the storage period. In 1893 the total rainfall was 42.36 inches, with a total run-off of 16.20 inches, the run-off of the storage period being 14.13 inches. In 1894 the rainfall dropped to a total of 30.51 inches and the run-off to a total of 8.70 inches, of which 7.63 inches occurred in the storage period. In 1895 the total rainfall was 29.84 inches and the total run-off 4.90 inches, of which 4.04 inches occurred during the storage period.

Genesee River, while not tributary to the Great Lakes above Niagara River, may still be cited as showing that at times the run-off of streams tributary to the Great Lakes is quite low. Referring to the table on page 70, giving the rainfall and run-off of Oatka Creek, a tributary of the Genesee, we learn that in the water year 1891, with a rainfall of 38.12 inches, the run-off was 14.05 inches. In 1892, with a rainfall of 41.69 inches, the run-off was 15.42 inches.

Taking the record of Genesee River proper, as given in the table on page 58, we learn that for the water year 1894, with a mean precipitation above the point of measurement of 47.79 inches, the run-off was 19.38 inches, of which 15.73 inches occurred in the storage period. In 1895 the rainfall dropped to 31 inches and the total run-off to 6.67 inches. In 1880 Hemlock Lake, a tributary of Genesee River, with a drainage area of 43 square miles and a total rainfall of 21.99 inches, gave a run-off of only about 3.4 inches.

[1] Survey of the Miami and Erie Canal, the Ohio Canal, etc. Report of Capt. Hiram M. Chittenden, Corps of Engineers, U. S. Army, January 20, 1896, printed as House Document No. 278, Fifty-fourth Congress, first session, p. 42.

Rainfall, run-off, evaporation, and mean temperature of Genesee River from December, 1893, to November, 1896, inclusive.

[In inches on the watershed.]

Month.	1894.				1895.				1896.			
	Rainfall.	Run-off.	Evaporation.	Mean temperature	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.
				°				°				°
December	3.39	2.34		26.8	2.47	0.61		29.0	3.80	1.32		30.1
January	3.91	1.40		28.4	3.26	0.66		1.91	2.29	0.47		22.4
February	2.93	0.86		20.1	1.22	0.22		14.5	3.56	0.91		22.9
March	1.62	3.31		37.9	1.72	1.94		28.0	4.00	3.00		22.7
April	7.22	3.39		42.1	2.10	2.01		44 2	1.62	3.38		47.7
May	8.64	4.43		54.5	2.43	0.19		57.8	2.57	0.17		60.7
	21.71	*15.73*	*11.98*	*35.0*	*13.20*	*5.63*	*7.57*	*32.1*	*17.84*	*9.25*	*8.59*	*34.4*
June	2.51	1.10		64.6	4.57	0.13		67.5	3.52	0.39		62.1
July	3.70	0.14		67.9	2.57	0.11		64.1	4.90	0.24		67.3
August	1.74	0.22		63.4	3.99	0.12		66.5	1.86	0.20		65.0
	7.95	*1.46*	*6.49*	*65.3*	*11.13*	*0.36*	*10.77*	*66.0*	*10.28*	*0.83*	*9.45*	*64.8*
September	6.97	0.93		61.6	1.96	0.10		61.7	5.22	0.16		57.5
October	3.50	0.44		49.5	1.30	0.11		41.8	4.08	1.74		43.6
November	1.66	0.82		32.1	3.41	0.47		38.0	3.26	0.82		41.6
	12.13	*2.19*	*9.94*	*47.7*	*6.67*	*0.68*	*5.99*	*47.2*	*12.56*	*2.72*	*9.84*	*47.6*
Year	47.79	19.38	28.41	45.7	31.00	6.67	24.33	44.3	40.68	12.80	27.88	45.3

These figures are cited to show that in years of low rainfall the run-off of streams tributary to the Great Lakes is very low, and as a consequence the run-off of Niagara River will probably be affected thereby. At present the data are insufficient for showing what the run-off of Niagara River really is.

The most elaborate measurements thus far made are those of the Lake Survey in 1867 and 1868, which are, however, extremely unsatisfactory. According to these measurements the mean discharge, rainfall, and evaporation from the Great Lakes for the year 1868, in cubic feet per second, were as follows:[1]

Mean discharge, rainfall, and evaporation from the Great Lakes for the year 1868, in cubic feet per second.

Lakes.	Mean discharge.	Total rainfall on basin.	Evaporation from surface.
Superior	86,000	171,430	27,690
Huron and Michigan	225,000	251,450	59,890
Erie	265,000	100,540	14,310
Total		523,220	101,890

[1] These figures are derived from Mr. Cooley's Lakes and Gulf Waterways, as corrected and given in the Journal of the Assoc. of Eng. Soc., Vol. VIII (March, 1889), p. 132.

According to the Deep Waterways Commission's tabulations of available records of heights of the Great Lakes, it appears that the water levels fluctuate through a series of years to the extent of about 4.5 feet. For the present discussion we are chiefly concerned with the fluctuations of Lake Erie, which control the discharge of Niagara River. By examination of the records of mean monthly elevation of Lake Erie at Buffalo from 1887 to 1897, as kept by the United States engineer's office at Buffalo, it appears that the highest mean monthly elevation during these years was for June, 1887, when the mean lake surface was +0.92. The lowest mean monthly elevation for the period was for March, 1896, when the mean for the month was −2.36. The range in the mean monthly elevations for this period was 3.28 feet.

Mean monthly elevation of Lake Erie at Buffalo.

[In feet with reference to datum.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.
December	.....	−0.26	−0.31	−0.71	−0.31	−1.35	−1.01	−0.92	−1.23	−2.08	−1.82
January	.....	−0.48	−0.49	−0.13	−0.57	−1.44	−1.78	−0.92	−1.36	−1.93	−1.47
February	.....	−1.09	−0.71	−0.31	−0.69	−2.13	−1.83	−1.30	−2.05	−2.00	−1.90
March	+0.60	−1.02	−1.10	−0.07	−0.55	−1.93	−1.52	−1.19	−2.13	−2.36	−1.39
April	+0.56	−0.36	−0.72	+0.18	−0.43	−1.09	−0.86	−1.00	−1.92	−1.83	−0.87
May	+0.78	−0.21	−0.56	+0.54	−0.65	−0.65	−0.14	−0.50	−1.57	−1 38	−0.45
	+0.64	*−0.57*	*−0.65*	*−0.08*	*−0.53*	*−1.43*	*−1.19*	*−0.97*	*−1.71*	*−1.93*	*−1.32*
June	+0.92	−0.04	−0.09	+0.87	−0.67	+0.16	+0.21	−0.11	−1.47	−1.37	−0.46
July	+0.76	+0.18	−0.05	+0.59	−0.49	+0.37	+0.08	−0.24	−1.49	−1.19	−0.48
August	+0.36	+0.07	−0.14	+0.12	−0.78	+0.00	−0.51	−0.71	−1.63	−0.96	−0.96
	+0.68	*+0.07*	*−0.09*	*+0.53*	*−0.65*	*+0.18*	*−0.07*	*−0.36*	*−1.53*	*−1.18*	*−0.63*
September	+0.05	−0.27	−0.52	−0.23	−0.95	−0.27	−0.76	−0.08	−1.61	−1.38	−1.40
October	+0.11	−0.46	−1.03	−0.25	−1.32	−0.60	−0.87	−0.88	−1.85	−1.64	−1.36
November	−0.44	−0.61	−1.03	−0.05	−1.38	−0.98	−0.88	−1.06	−2.34	−1.61	−1.24
	−0.09	*−0.45*	*−0.86*	*−0.17*	*−1.22*	*−0.62*	*−0.84*	*−0.67*	*−1.93*	*−1.54*	*−1.33*
Year	*a*+0.41	−0.38	−0.56	+0.05	−0.73	−0.83	−0.82	−0.74	−1.72	−1.64	−1.15

a Mean of nine months.

Temporarily much greater fluctuations have been experienced, due largely to wind action, to which Lake Erie, on account of its shallowness, and the fact that its general direction is favorable for the sweep of the prevailing winds, is peculiarly subject. In regard to the measurements of the Lake Survey, it may be remarked that they indicate large variations in discharge from all of the lakes, from the effects of winds and other disturbing causes, but give little clew to the quantities at either of the extremes of high or low water. According to Lyman E. Cooley the extreme low-water discharge is probably 20 to 30 per cent less than the Lake Survey figures, and extreme high water 20 to 30 per cent more.

Measurements of the amount of water flowing in Niagara River were begun in December, 1891, at a time when the water in Lake Erie was very low and the conditions were considered especially favorable for

minimum discharge. The results are given in the Annual Report of the Chief of Engineers, United States Army, for 1893, Part VI, pp. 4364–4371. The point selected was about 1,000 feet below the International Bridge at Black Rock, near the foot of Squaw Island, at which point the river is free from eddies. Niagara River, on leaving Lake Erie, has a nearly straight channel about 2,000 feet wide for the first 2 miles. The fall in this section is from 4 to 5 feet, and the velocity ranges from 7 miles per hour at the upper end to about 5 miles at the lower end. The point was chosen, after careful consideration, as the point in that vicinity least subject to disturbance. In taking the cross sections, the width, which varies slightly with different stages of the river, was actually determined for gage readings 1 foot apart, and for extreme points the width was determined by interpolating values derived from the known slope of the river banks. A local gage was established at the draw pier of the International Bridge by setting gage boards on each side of the pier, with the zeros of the gages on the same level. The local gage was read at the beginning and close of all velocity observations, and the gage at Buffalo was read at 7 a. m. and 1 and 7 p. m. The zero of this latter gage is at the mean level of Lake Erie, or 572.23 feet above mean tide at New York, in the Erie Canal levels, or as used by the Government engineers, 572.96 feet. During the velocity observations in December, 1891, Lake Erie was about 1.5 feet below its mean level, and is stated not to have been seriously affected by strong winds. Still the daily record shows that there must have been some wind action. The current velocities were obtained after the methods used by the Mississippi River Commission and described in their reports, all velocity observations being taken with a current meter, with electrical appliances for recording the number of revolutions. The following are some of the results obtained:[1]

Mean heights and discharge of Niagara River.

Date.	Mean height on local gage.	Mean height on Buffalo gage.	Discharge per second.
1891.	*Feet.*	*Feet.*	*Cu. feet.*
December 24	0.05	—2.95	164,648
December 14	0.65	—1.85	191,822
December 21	0.735	—1.75	193,522
December 20	0.835	—1.75	201,433
December 22	1.125	—1.45	208,597
December 10	1.33	—0.50	218,353
1892.			
May 19	1.562	—0.80	213,180
May 7	1.750	—0.85	218,988
May 24	2.292	+0.15	236,762

[1] Annual Report of Chief of Engineers, United States Army, 1893, Part VI, p. 4367.

The table shows (1) a variation in lake elevation, as indicated in the Buffalo gage, from —2.95 on December 24, 1891, to +0.15 on May 24, 1892, a range of 3.10 feet; (2) a variation in discharge of 72,114 cubic feet per second. There are some discrepancies in the results which it is not necessary to discuss at length; but in the absence of more satisfactory data we may assume, in view of the foregoing evidence as to the small run-off of streams tributary to and in the vicinity of the Great Lakes, that the figures obtained in the fall of 1891 and spring of 1892 are probably more nearly correct than the larger figures of the Lake Survey. By plotting the observed discharges a mean discharge curve has been obtained, from which the discharge of the river at points within the range of the observation can be taken off, when one has the tabulated heights of the Buffalo gage before him. At present these measurements are, on the whole, not considered sufficiently exact to justify the labor of preparing a tabulation of this character.[1]

Referring to the table on page 58, it is learned that the rainfall in that portion of the basin of the Great Lakes tributary to Niagara River was, for 1868, 523,220 cubic feet per second, and the evaporation from the water surface of the lakes tributary to Niagara River was 101,890 cubic feet per second. Hence the evaporation from the lake surfaces was nearly 20 per cent of the rainfall on the whole basin. Assuming for the moment the truth of these figures, we have 80 per cent of the total rainfall from which the land evaporation must be deducted before anything can run off. Again assuming the land evaporation at 1.70 feet, there results a loss from this source alone of 298,000 cubic feet per second; adding to this the evaporation loss from the water surfaces gives a total evaporation loss of 399,890 cubic feet per second. The run-off is the difference between rainfall and total evaporation losses. If, therefore, the land evaporation was 1.7 feet for the year 1868, the run-off would have been in reality only 123,330 cubic feet per second instead of 265,000 cubic feet per second, as

[1] There have been a number of independent measurements of volume of the Niagara, and though the results differ widely, they probably do not differ more than the actual volume of the river at various stages of Lake Erie.

Lyell (1841 ?) quotes Ruggles as authority for a volume of 250,000 cubic feet per second.

E. R. Blackwell, computed by Allen (Am. Jour Sci., 1841), obtains 374,000 cubic feet per second. His work was afterwards recomputed by D. F. Henry, who obtained 244,797 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1867-68, D. F. Henry gives as a result of observations in August and September, 1867, 242,494 cubic feet per second. A year later he recomputed from the same data, and obtained 240,192 cubic feet per second. He also made a new measurement by a different method (see Report for 1868-69) from which he obtained two results, 304,307 and 258,586 cubic feet per second.

W. F. Reynolds (annual report of the Chief of Engineers, United States Army, 1870?), gives the result of observations from June to September, 1869, 212,860 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1871, there is mention of a result, without date of measurement, 245,296 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1891-92, Quintus, as a result of gaging, gives the volume, reduced to mean stage, as 232,800 cubic feet per second.

Sir Casimir S. Gzowski, from continuous observations at the International Bridge, 1870-1873, gives an average discharge for that period of 246,000 cubic feet per second.

determined by the Lake Survey. These figures, while not conclusive, are suggestive, so much so, indeed, that taking into account all the conditions it seems clear that in a series of years of minimum rainfall the run-off of the Great Lakes, tributary to Niagara River, may be as low as from 6 to 9 inches a year on the watershed. At the former figure the mean discharge would be about 177,700 cubic feet per second.[1]

As an additional source of loss from the Great Lakes the proposed ultimate diversion of 10,000 cubic feet per second through the Chicago drainage canal to the head waters of Illinois River may be referred to. Thus far the discussion of such loss has been mainly conducted on the supposition that the mean discharge of the Great Lakes at Niagara was about 265,000 cubic feet per second. If this were true the ultimate injurious effect of such diversion could only appear during a series of extremely dry years. The author can not but think that this whole question of the run-off of Niagara River has become fogged by a discussion based thus far purely on averages. What we really want to know is the run-off of a cycle of dry years. With such data we can compute the effect of a given diversion more satisfactorily than when dealing with means.

With a cycle of rainfall years, either high or at about the average, it is probable that very little effect from such diversion will be observed, the consensus of opinion at the present time apparently being that it will not exceed about 0.3 to 0.4 foot in depth over the areas affected. Owing to the balancing of conditions due to the immense pondage of the Great Lakes, and which requires years in order to complete a cycle, it is uncertain whether the abstraction of 10,000 cubic feet per second at Chicago would be especially detrimental at Niagara Falls, although in years of extreme low flow it is probable that it would be easily apparent. If, however, the minimum flow of Niagara River is really as low as 150,000 to 180,000 cubic feet per second, it is clear that the loss of 10,000 cubic feet per second will be a matter worth taking into account.

In the discussion of the effect of diverting 10,000 cubic feet per second at Chicago on the levels of the Great Lakes, by Lyman E. Cooley, which appears in the proceedings of the annual convention of the International Deep Waterways Association, held at Cleveland in September, 1895, it is stated that assuming the correctness of the

[1] By way of illustrating further the probable inaccuracy of the Lake Survey figures, it may be pointed out that if the determination of evaporation from the water surfaces at 101,890 cubic feet per second and run-off at 265,000 cubic feet per second for the year 1868 is correct, the total outgo from these two sources was 368,890 cubic feet per second, leaving the land evaporation for that year at 156,330 cubic feet per second, or at 0.9 foot over the watershed.

By studying the evaporation of the Upper Mississippi reservoirs, the Des Plaines and Muskingum rivers, and other streams herein referred to, it will readily be seen that it is exceedingly improbable that a land evaporation as low as 0.9 foot ever occurred over the whole watershed of the Great Lakes.

figures derived from the Lake Survey placing the mean discharge of St. Clair River at 225,000 cubic feet per second, the abstraction of 10,000 cubic feet per second would diminish the mean outflow in St. Clair River by nearly 4.5 per cent and in Niagara River by about 3.75 per cent. Mr. Cooley says that, reasoning on lines obvious to those unacquainted with hydraulic principles, it is apparent that the ruling depth in the rivers at mean level can not be lessened by an amount greater than the percentages just stated; but if we consider the question as an hydraulic proposition, taking into account the relation of mean radius to area and perimeter, it is apparent that the effect on lake levels would be only a fraction of that indicated by the reduction in volume.

The literature of the discharge of Niagara River and of the probable effect on the lake levels of abstracting 10,000 cubic feet per second at Chicago has now grown so extensive as to preclude further discussion of the question here. Those wishing to pursue the subject further may consult the references given in the footnote. Concluding the subject, it may be stated that the studies of the Lake Survey indicate a mean discharge of Niagara River of about 265,000 cubic feet per second, with a range above and below the mean of from 20 to 30 per cent. The only measurements since made were those of December to May, 1891–92, which indicate a minimum discharge as low as or even lower than 141,000 cubic feet per second, this latter figure agreeing fairly well with theoretical considerations derived from present knowledge of the actual minimum run-offs of contiguous drainage areas.[1]

[1] For literature of discharge of Great Lakes and allied questions see (1) Repts. Chief of Engnrs. 1868, 1869, 1870, and 1882; (2) Repts. Chief of Engnrs., 1893; (3) Eng. News, Vol. XXIX (March 2, 1893); (4) The Lakes and Gulf Waterways, by L. E. Cooley; (5) The level of the Lakes as affected by the proposed Lakes and Gulf waterway, a discussion before the Western Society of Engineers, in Jour. of the Assn. of Eng. Socs., Vol. VIII (Mch., 1889); (6) An enlarged waterway between the Great Lakes and the Atlantic seaboard, by E. L. Corthell, with discussion, in Jour. of the Assn. of Eng. Socs., Vols. X and XI (April, June, and December, 1891, and July, 1892); (7) Lake level effects on account of the sanitary canal at Chicago, by L. E. Cooley, in Proc. Internat. Deep Waterways Con., at Cleveland, Sept., 1895; (8) A technical brief, by Thomas T. Johnston, covered by the preceding reference; (9) Papers by William Pierson Judson, on an Enlarged waterway between the Great Lakes and the Atlantic seaboard, pamphlets, 1890 and 1893.

Rainfall and run-off of Des Plaines River, as determined by the Chicago drainage commission, from 1886 to 1897.

[Inches on watershed.]

Months.	1886.		1887.		1888.		1889.		1890.		1891.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	-------	-------	1.76	0.00	3.67	-------	1.94	0.00	1.90	-------	-------	-------
January	-------	-------	3.13	0.89	1.56	1.37	1.64	0.29	-------	-------	-------	-------
February	-------	-------	5.10	5.59	1.51	2.50	1.31	0.01	-------	-------	-------	-------
March	-------	-------	0.89	2.64	2.99	4.84	1.43	0.43	-------	-------	-------	-------
April	-------	-------	0.46	0.52	-------	-------	2.35	1.13	-------	-------	-------	-------
May	-------	-------	1.38	0.13	-------	-------	5.38	0.39	-------	-------	-------	-------
			12.72	*9.77*	-------	-------	*14.05*	*2.25*	-------	-------	-------	-------
June	0.94	0.16	1.63	0.02	-------	-------	2.93	1.26	-------	-------	-------	-------
July	1.53	0.14	1.05	0.33	-------	-------	9.56	1.09	2.57	-------	-------	-------
August	3.38	0.01	3.35	0.18	-------	-------	0.39	0.45	2.58	0.02	-------	-------
	5.85	*0.31*	*6.03*	*0.53*	-------	-------	*12.88*	*2.80*	-------	-------	-------	-------
September	6.93	0.03	4.03	0.22	0.98	-------	2.75	0.00	1.39	0.01	-------	-------
October	1.42	0.01	2.03	0.63	2.95	0.00	1.82	0.00	4.20	0.02	-------	-------
November	1.66	0.00	2.41	-------	2.89	0.00	3.49	0.01	1.59	0.04	-------	-------
	10.01	*0.04*	*8.47*	-------	*6.82*	-------	*8.06*	*0.01*	*7.18*	*0.07*	-------	-------
Year	-------	-------	27.22	-------	-------	-------	34.99	5.06	-------	-------	-------	-------

Months.	1892.		1893.		1894.		1895.		1896.		1897.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rain. fall.	Run-off.	Rainfall.	Run-off.
December	-------	-------	1.63	0.04	2.14	0.27	1.66	-------	6.76	1.80	0.16	0.19
January	-------	-------	2.08	0.01	1.55	0.50	2.15	-------	1.12	0.26	4.53	-------
February	-------	-------	2.44	0.31	2.13	1.06	1.60	0.21	3.48	1.06	2.22	1.39
March	-------	-------	1.69	5.15	2.66	3.05	1.32	0.71	1.26	1.11	3.56	4.61
April	-------	-------	4.16	1.79	2.65	0.76	0.86	0.29	2.79	0.77	2.23	1.88
May	6.77	4.24	1.93	1.31	3.35	1.90	1.99	0.11	4.16	0.39	0.84	0.60
			13.93	*8.61*	*14.48*	*7.54*	*9.58*	-------	*19.57*	*5.39*	*13.54*	-------
June	10.58	6.04	3.59	1.37	1.96	0.08	1.79	0.00	2.82	0.09	-------	-------
July	2.23	0.79	3.08	0.14	0.60	0.01	2.42	0.00	3.61	0.02	-------	-------
August	1.85	0.03	0.18	0.00	0.60	0.00	6.49	0.01	3.52	0.06	-------	-------
	14.66	*6.86*	*6.85*	*1.51*	*3.16*	*0.09*	*10.70*	*0.01*	*9.95*	*0.17*	-------	-------
September	1.34	0.02	1.98	0.00	8.28	0.06	0.89	0.06	6.54	0.32	-------	-------
October	1.54	0.00	1.75	0.02	0.84	0.00	0.51	0.00	1.36	0.33	-------	-------
November	2.68	0.02	2.45	0.00	1.18	0.01	5.60	0.00	2.16	0.48	-------	-------
	5.56	*0.04*	*6.18*	*0.02*	*10.30*	*0.07*	*7.00*	*0.06*	*10.06*	*1.13*	-------	-------
Year	-------	-------	26.96	10.14	27.94	7.70	27.28	-------	39.58	6.69	-------	-------

Evaporation from the Des Plaines watershed, as given by differences between rainfall and run-off in the preceding table.

[Inches on watershed.]

Water year.	December to May.	June to August.	September to November.	Total.
1886		5.54	9.97	
1887	2.95	5.50		
1889	11.80	10.08	8.05	29.93
1890			7.11	
1892		7.80	5.52	
1893	5.32	5.34	6.16	16.82
1894	6.94	3.07	10.23	20.24
1895		10.69	6.94	
1896	14.18	9.78	8.93	32.89

RUN-OFF OF ST. LAWRENCE RIVER.

According to the report of the Deep Waterways Commission, the area of the water surface of Lake Ontario is 7,450 square miles, and the area of the tributary watershed, exclusive of the area of the lake itself, 25,530 square miles. The total area of the drainage basin, including both land and water surfaces, is 32,980 square miles. The area of the water surface of St. Lawrence River from Gallops Rapids to Montreal[1] is given at 220 square miles, and the area of the tributary watershed at 5,710 square miles; hence the total area of the basin of the St. Lawrence from Gallops to Montreal becomes 5,930 square miles.

In the foregoing figures Lake Ontario is considered as beginning in Niagara River, at the foot of Niagara Falls and terminating at the head of Gallops Rapids, whence the following subdivisions of water-surface area are derived: Niagara River, 5 square miles; Lake Ontario proper, 7,260 square miles; St. Lawrence River, 185 square miles; giving a total, as above, of 7,450 square miles.

Of the total area of watershed of 25,530 square miles, 14,275 square miles lie within the State of New York and 11,255 square miles in the Province of Ontario. The standard low-water elevation of Lake Ontario is taken as 244.53 feet, and the standard high-water elevation as 249.04 feet above tide.

St. Lawrence River is considered as beginning at Gallops Rapids. The following table gives the elevation of water surface at a number of points.[2]

[1] Report of U. S. Deep Waterways Commission, 1897, House Document No. 192, Fifty-fourth Congress, second session, pp. 151-153.

[2] Report of U. S. Deep Waterways Commission, 1897, p. 152.

Elevation above tide of low-water and high-water surface of St. Lawrence River.

Locality.	Standard low water.	Standard high water.
	Feet.	*Feet.*
Ogdensburg	244.28	248.57
Lake St. Francis, at Valleyfield	153.50	155.94
Lake St. Louis, at Melicheville	70.0	77.50
Montreal	23.10	35.78

The area of water surface of the St. Lawrence from Gallops Rapids to Montreal is 220 square miles, and the total area of watershed not included in the surface of the river is 5,710 square miles, of which 3,800 square miles lie in New York, 620 in Ontario, and 1,290 in Quebec. The total area of the drainage basin, including water surface of the river, is 5,930 square miles.

The only measurements as to the discharge of St. Lawrence River thus far made are those of the Lake Survey, which give a mean discharge of 300,000 cubic feet per second. The recent data would indicate that this figure is somewhat too large, as in the Lake Survey discharge of Niagara River. The streams tributary to Lake Ontario, however, issue from a region of heavier rainfall than those tributary to the Upper Great Lakes and, as shown by the run-off tables of this report, are generally much better water yielders. Taking everything into account, it is probable that the minimum discharge of St. Lawrence River will not be less than from 8 to 10 inches over the entire watershed per year. A run-off of 12 inches per year over the entire drainage basin would give a mean discharge of 234,300 cubic feet per second, or a discharge of 0.884 cubic foot per square mile per second. A mean discharge of 300,000 cubic feet per second, as measured by the Lake Survey, would give 1.13 cubic feet per square mile per second. These figures are for the minimum discharge; for years, or cycles of years, of average rainfall the run-off would be more.

RUN-OFF OF INLAND STREAMS OF NEW YORK.

The data for determining the run-off of the inland streams of New York are included in the tables given on pages 67 to [illegible] lowing. The results of measurements on Oatka Cr[illegible] Genesee River, with a drainage area of 27.5 squar[illegible] point of measurement, from April, 1890, to Novembe[illegible] on page 70. The discharge of Genesee River at Mou[illegible] which point the drainage area is 1,070 square miles, from December, 1893, to November, 1896, is given on page 58. The table on pages 76 and 77 shows the quantity of water drawn from Hemlock Lake, also a tribu-

tary of Genesee River, and with a drainage area above the point of measurement of 43 square miles, for the water years 1880 to 1884, inclusive. The table on page 78 gives a similar tabulation of water drawn from Skaneateles Lake for the months indicated from October, 1890, to November, 1897, inclusive. The tables on page 82 give the run-off of Hudson River as measured at Mechanicville, where the drainage area is 4,500 square miles, from October, 1887, to November, 1896, inclusive. The table on pages 83 to 85 gives the run-off of Croton River, as measured at the Croton dam, where the drainage area is 338 square miles, for the water years from 1870 to 1896, inclusive. The table on page 72 presents measurements at Rochester in comparison with those at Mount Morris. So far as the author can learn, the foregoing include all the systematic measurements of streams, for considerable periods, thus far made in the State of New York, except those by John B. Jervis of the Madison and Eaton brooks in 1835, the results of which are presented in his report for that year to the canal commissioners.[1]

DISCHARGE MEASUREMENTS OF EATON AND MADISON BROOKS.

Eaton and Madison brooks, of which measurements were made by Mr. Jervis in 1835, are in the central-eastern part of Madison County and tributary to Chenango River. The drainage area of Eaton Brook is given by Mr. Jervis at 6,800 acres, or 10.6 square miles, and that of Madison Brook as 6,000 acres, or 9.4 square miles.

Rainfall and run-off of Eaton Brook.

Month.	Rainfall.	Rainfall for 6,800 acres.	Run-off from 6,800 acres.	Percentage of run-off to rainfall.
1835.	*Inches.*	*Cubic feet.*	*Cubic feet.*	
June	6.72	165,876,480	59,407,394	35.8
July	2.74	67,634,160	27,994,240	41.4
August	2.86	70,596,240	13,547,058	19.2
September	1.34	33,076,560	9,586,513	29.0
October	3.0	74,052,000	20,694,651	27.2
November	2.20	54,304,800	23,772,620	43.8
December	0.96	23,696,640	36,525,544	54.1
June to December, inclusive	19.82	489,236,880	191,528,020	39.2
June to October, inclusive		411,235,440	131,229,856	31.9

[1] The measurements for short periods of several streams and of the water supply of Brooklyn are not overlooked in this statement, which is intended to apply to measurements extending over a year or more.

Rainfall and run-off of Madison Brook.

Month.	Rainfall.	Rainfall for 6,000 acres.	Run-off from 6,000 acres.	Percentage of run-off to rainfall.
1835.				
Snow of November–December, 1834, on ground	*Inches.*	*Cubic feet.* 87,120,000	*Cubic feet.*	
January	2.17	47,262,600	23,192,079	49.1
February	2.50	54,450,000	35,377,594	64.9
March	1.03	22,443,400	43,284,656	192.8
April	5.0	108,900,000	80,776,974	74.1
May	1.98	43,124,400	58,013,176	134.5
June	8.05	175,329,000	20,138,006	11.5
July	3.87	84,288,600	23,141,302	27.4
August	3.06	66,646,800	23,725,060	35.6
September	0.88	19,166,400	19,158,957	99.9
October	3.86	84,070,800	19,544,880	23.2
November	2.10	45,738,000	18,232,372	39.9
December	0.76	16,552,800	19,401,364	117.2
January to December, inclusive	35.26	855,092,800	383,986,420	44.9
January to May, inclusive		363,300,400	240,644,479	66.2
June to October, inclusive		429,501,600	105,708,205	24.6

The following statements in regard to these measurements are abstracted from Mr. Jervis's report:[1] From the Eaton Brook results it appears that the average run-off from June to December, inclusive, was 39.2 per cent of the rainfall and from June to October, inclusive, 31.9 per cent of the rainfall. The minimum monthly run-off was in August, which shows only 19.2 per cent of the rainfall. The rainfall in the month of June, 1835, on Eaton Brook was 6.72 inches and in July 2.74 inches. The percentage of run-off to rainfall for June was 35.8, whereas for July it was 41.4, which would indicate that the bulk of the June rain must have been at the end of the month.

[1] For Mr. Jervis's original report see Appendix F to Ann. Rept. Canal Com., 1835, Ass. Doc. No. 65, pp. 55–60. Mr. Jervis's tables, with extracts from the report, are also quoted in the following documents:

(1) Report of F. C. Mills, chief engineer Gen. Val. Can., in Appendix D to Ann. Rept. Can. Com., 1837, Ass. Doc. No. 80, p. 81.

(2) Report of W. H. Talcott, Res. Eng. Gen. Val. Can., 1840, Ass. Doc. No. 96, p. 51.

(3) Report of the Regents of the University, 1838, Sen. Doc. No. 52, pp. 208–211.

(4) Documentary History of the New York State Canals. By S. H. Sweet, Dep. State Eng. and Sur., 1863, Ass. Doc. No. 8, pp. 203–204.

From the measurements of Madison Brook it appears that in 1835 the average run-off for the whole year, including the snow on the ground on January 1, was 44.9 per cent, or nearly one-half of the rainfall. Mr. Jervis points out that on account of the storage of the reservoir Madison Brook record can not be taken for the summer months, but that the year should be divided into two periods. For the first period he gives the results from January to May, inclusive, during which the run-off was 66.2 per cent of the rainfall, and for the second from June to October, during which the run-off was 24.6 per cent of the rainfall. During the second period, June to October, inclusive, Eaton Brook gave a run-off of 31.9 per cent of the rainfall. Mr. Jervis explains these different results by the different characters of the two districts drained. Eaton Brook Valley is very narrow and the area drained quite steep, with a very close-textured soil. Madison Brook Valley, on the other hand, is much wider, with easy slopes, and the soil in a portion of it is more porous than that on Eaton Brook. Mr. Jervis concludes his discussion with the remark that Eaton Brook Valley would afford more than an average run-off over a large district of country including the usual varities of soil, while Madison Brook would probably not differ materially from the general average in this State.

In his documentary history of the New York State canals, which is included in the annual report of the State engineer and surveyor for the fiscal year ending September 30, 1862, S. H. Sweet analyzes Mr. Jervis's measurements of discharge of Eaton and Madison brooks and points out several probable errors, especially in the Madison Brook result, where, because the measurements indicate only what was actually discharged through the sluice pipes each day instead of what drained off from the valley, he concludes that the real drainage of the Madison Brook area in 1835 was about 0.518 of the rainfall, instead of 0.449, as given by Mr. Jervis. Inasmuch as the Eaton Brook and Madison Brook measurements have only historical interest at the present time, this branch of the subject is not here pursued at length. So far as can be learned, the measurements of these two streams by Mr. Jervis, in 1835, were the first systematic measurement of the run-off of streams in the United States. Geologically these streams lie in the horizon of the Hamilton shales.

DISCHARGE MEASUREMENTS OF OATKA CREEK.

The measurements of Oatka Creek, recorded in the following table, were made at the milldam in the south part of the village of Warsaw, in Wyoming County. The dam was new, practically tight, and well adapted for securing accurate results. Measurements were also made of the outflow of the head race way leading from the dam for different elevations of water on the dam, and a curve prepared from which the discharge of the race way was read off and added to the discharge over

the dam as computed by Francis's weir formula. It is believed that the results are accurate within a very small per cent.

Rainfall, run-off, evaporation, and mean temperature of Oatka Creek drainage area.

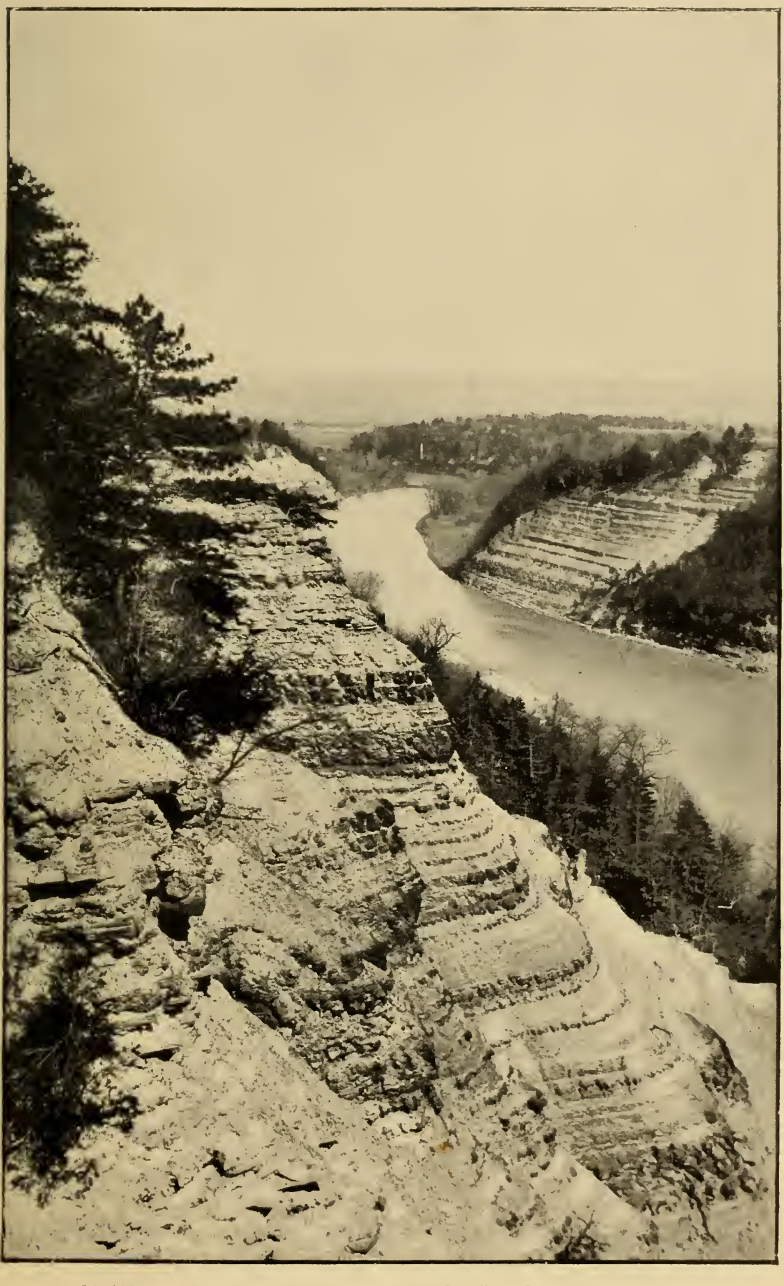
[In inches on the watershed.]

Months.	1890.				1891.				1892.			
	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.
				°				°				°
December	3.33	.....	.....	37.0	2.61	0.97	.....	24.6	3.80	1.04	.....	34.9
January	4.36	.....	.....	32.7	4.12	2.62	.....	26.1	3.82	0.78	.....	21.0
February	3.63	.....	.....	31.5	4.67	3.40	.....	29.0	3.71	1.66	.....	26.9
March	2.72	.....	.....	29.5	3.70	2.87	.....	29.9	1.73	1.94	.....	26.1
April	2.82	2.17	.....	44.7	1.52	1.39	.....	45.7	1.04	2.21	.....	42.1
May	6.15	3.16	.....	52.8	1.60	0.63	.....	52.8	5.74	1.75	.....	50.0
	23.01	.....	.....	*38.0*	*18.22*	*11.38*	*6.34*	*34.7*	*19.84*	*9.38*	*10.46*	*31.8*
June	4.12	1.85	.....	67.4	4.01	0.44	.....	65.2	6.67	1.41	.....	67.2
July	3.18	0.38	.....	70.2	4.52	0.37	.....	63.9	4.18	2.06	.....	68.1
August	3.22	0.28	.....	66.8	4.25	0.25	.....	65.4	4.45	1.43	.....	67.1
	10.52	*2.51*	*8.01*	*68.1*	*12.78*	*1.06*	*11.72*	*64.8*	*15.30*	*4.90*	*10.40*	*67.5*
September	6.59	1.35	.....	60.3	1.72	0.46	.....	62.5	1.62	0.24	.....	59.0
October	4.52	2.27	.....	50.2	2.49	0.24	.....	46.6	2.19	0.33	.....	47.2
November	2.90	2.13	.....	39.3	2.91	0.41	.....	36.5	2.74	0.57	.....	35.0
	14.01	*5.75*	*8.26*	*49.9*	*7.12*	*1.11*	*6.01*	*48.5*	*6.55*	*1.14*	*5.41*	*47.1*
Year	47.54	.....	.....	48.5	38.12	14.05	24.07	45.7	41.69	15.42	26.27	45.4

The drainage area of Oatka Creek above Warsaw includes 27.5 square miles of rolling semimountainous country. The valley of the creek is deep cut, with numerous springs at the head waters. The drainage area is mostly deforested and in a high state of cultivation, the soil inclining to clay for a considerable portion. Geologically the stream lies in the rocks of the Portage formation, as developed in western New York. The run-off from this area may be taken as fairly typical of many small streams in western New York.

DISCHARGE MEASUREMENTS OF GENESEE RIVER.

The measurements of Genesee River proper, presented in the table on page 58, were made at the timber dam of the Mount Morris Hydraulic Power Company from September, 1893, to November, 1896, inclusive. The crest of this dam is quite irregular, and, in order to apply weir formulæ to it, an accurate profile was taken and the dam divided into a number of approximately level sections, with each section computed separately for various heights and advancing by 0.1 of a foot up to 10 feet. Working on this plan, the flow over the entire dam, which is 337 feet in length, was obtained by adding together the sums of the several sections at the corresponding heights and tabulating these. A gage graduated to 0.05 foot was erected on the river bridge



CANYON OF GENESEE RIVER BETWEEN MOUNT MORRIS AND PORTAGE.

a short distance away, with its zero level coinciding with the lowest point of the dam. During ordinary stages of the river readings of this gage were taken twice each day, but in time of high water, in order to obtain the movement of floods as accurately as possible, readings were taken several times a day. In order to compute the flow readily a curve was projected, embodying the data of the tabulation previously referred to, and from which, with the given gage heights, the flows in cubic feet per second could be quickly read off.

When the measurements were first begun, it was considered that the formula $Q = 1142\ H^{\frac{3}{2}}$ was best suited to the form of the dam, but after more careful consideration it was apparent that the results given by this formula were somewhat in excess of the actual discharge, especially for the low-water flows. Accordingly a weir was constructed during the summer of 1896, at a point 2.5 miles above the Hydraulic Power Company's dam, where rock bottom clear across the river offered a convenient opportunity for such construction without heavy expense. This weir was made perfectly tight.

In order to correlate the measurements at the Mount Morris Hydraulic Power Company's dam with those of the weir, two observations a day were taken at each place, nearly at the same time; that is to say, they were both taken by the same man, who passed immediately from the weir to the dam and vice versa. Observations on the weir were obtained up to a head of 4 feet, and the corresponding discharge computed with the proper allowance for velocity of approach, etc. The depths on the Hydraulic Power Company's dam corresponding to the given depths on the weir were so plotted on the diagram as to give at once the relation between the flow at the weir and the depth on the crest of the Hydraulic Power Company's dam. By proceeding in this way the dam was accurately rated up to a discharge of 5,000 cubic feet per second. For discharges beyond 5,000 cubic feet per second the original determination has been used. An extension of the plotted curves shows that some little distance above 5,000 cubic feet per second discharge the results of the two methods are substantially the same. The two curves crossed at the point of about 6,000 cubic feet per second discharge. For discharges above 10,000 or 15,000 cubic feet per second there is probably an error in the results of from 5 to 10 per cent. Below 5,000 cubic feet per second it is believed that the results are now accurate within 2 or 3 per cent. Francis's formula, $Q = 3.33\ L\ H^{\frac{3}{2}}$ has been used for the weir computations.

The measurements taken previously to the construction of the weir and the rating of the dam, as aforesaid, have all been corrected to conform to the new determinations; hence all the data of the Genesee measurements of this table may be considered as accurate within the limits stated.

Discharge measurements of Genesee River have also been kept for the last three years at Rochester, where the drainage area is about 2,400 square miles. From data obtained during the summer of 1895 it was apparent that these measurements also require a correction in order to give the approximate true flow of the stream during the period covered. Without going into detail it may be stated that the Rochester measurements in the following table give the corrected results, which are now probably accurate within from 5 to 10 per cent:

Comparison of the measurements of Genesee River at Rochester with those at Mount Morris for the water years 1894 to 1896, inclusive.

[In cubic feet per second, and with yearly means also in inches on the watershed.]

Month.	1894.			1895.			1896.		
	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*
December	3,914	3,914	4,797	1,459	1,100	1,256	1,839	1,700	2,710
January	2,841	2,841	2,867	1,619	1,200	1,335	1,645	1,400	964
February	2,584	2,584	1,954	977	700	495	2,702	2,702	2,005
March	6,008	6,008	6,794	4,035	4,035	3,985	3,725	3,725	6,158
April	5,646	5,646	7,172	3,083	3,083	4,257	7,623	7,623	7,172
May	6,304	6,304	9,080	1,309	900	385	1,576	1,300	347
	4,576	*4,576*	*5,477*	*2,099*	*1,848*	*1,958*	*3,181*	*3,054*	*3,218*
June	2,951	2,800	2,321	885	535	283	1,317	1,000	654
July	1,055	792	292	645	390	232	854	645	501
August	973	732	442	600	400	254	585	440	416
	1,656	*1,426*	*1,003*	*728*	*440*	*256*	*977*	*692*	*522*
September	1,664	1,500	1,963	407	250	221	324	240	327
October	1,226	920	899	366	220	230	2,271	2,000	3,667
November	1,782	1,600	1,729	834	500	993	993	745	1,728
	1,573	*1,335*	*1,523*	*534*	*333*	*478*	*1,353*	*1,006*	*1,926*
Year	3,088	2,978	3,370	1,364	1,116	1,163	2,174	1,951	2,220
Inches on watershed.	19.20	18.35	19.38	8.48	6.41	6.67	12.48	11.20	12.80

a Increased in proportion to increased drainage area at Rochester.

As interesting data from Genesee River measurements, we may discuss the flood of May 20–23, 1894, at which time the approximate discharge of the stream at Mount Morris, from a drainage area of 1,070 square miles, was as follows:

Discharge of Genesee River at Mount Morris during the flood in May, 1894.

	Cubic feet per second.
May 18, 7 a. m	600
May 18, 6 p. m	3,090
May 19, 7 a. m	5,530
May 19, 6 p. m	5,090
May 20, 7 a. m	16,580
May 20, 12 m	22,210

Discharge of Genesee River at Mount Morris during the flood in May, 1894—Cont'd.

	Cubic feet per second.
May 20, 6 p. m	28,000
May 21, 3.30 a. m	42,000
May 21, 7 a. m	33,000
May 21, 12 m	30,730
May 21, 6 p. m	26,500
May 22, 7 a. m	15,650
May 22, 12 m	13,650
May 22, 6 p. m	10,720
May 23, 7 a. m	7,300
May 23, 12 m	6,700
May 23, 6 p. m	5,690
May 24, 7 a. m	5,390

The total run-off from 7 a. m. of May 19 to 7 a. m. of May 24 was nearly 6,900,000,000 cubic feet.

On the morning of May 21 the flats in the broad, level valley of

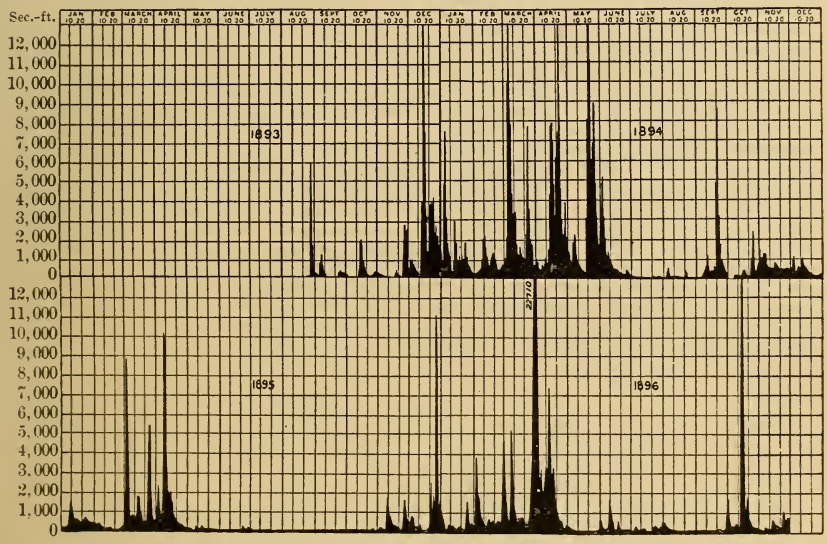


FIG. 2.—Discharge of Genesee River at Mount Morris, New York, 1893 to 1896.

Genesee River and Canaseraga Creek, between Dansville, Mount Morris, and Rochester, and which have an area of from 60 to 80 square miles, were nearly flooded, in some localities to a depth of from 4 to 6 feet. On account of the large pondage by these flats, although the maximum run-off at Mount Morris was 42,000 cubic feet per second at 3.30 a. m. on the morning of May 21, at Rochester the maximum flow did not at any time exceed about 20,000 cubic feet per second. We have, then, a case where a large pondage has, by prolonging the time of run-off, modified a flood flow over 50 per cent. As further illustrating the effect of a large reservoir, or, what is the same thing, the effect of a large pond area in modifying the effect of an extreme

flood, reference may be made to fig. 3, in which, with time as abscissas and run-off as ordinates, the run-off record of Genesee River for May 18–24, 1894, has been plotted. The lower curve of that figure may be taken as representing approximately the law of the run-off of any generally distributed heavy rainfall on the catchment area of this stream. In making this statement it is not overlooked that flood flows at other seasons of the year may differ somewhat in their movement from that of May, 1894. Inasmuch as the rapidity and intensity of the run-off of any given stream depend largely upon the topography, the statement may be made that the general law of movement of floods in Genesee River is indicated by the lower curve of fig. 3. With this understanding we may assume any other run-off and construct the approximate curve by drawing it generally parallel to the curve of the actually observed case. In this way the upper curve of fig. 3, representing the curve of a flood one and one-half times greater than that of May, 1894, has been produced, slight irregularities of the lower curve having been neglected in projecting the upper one.

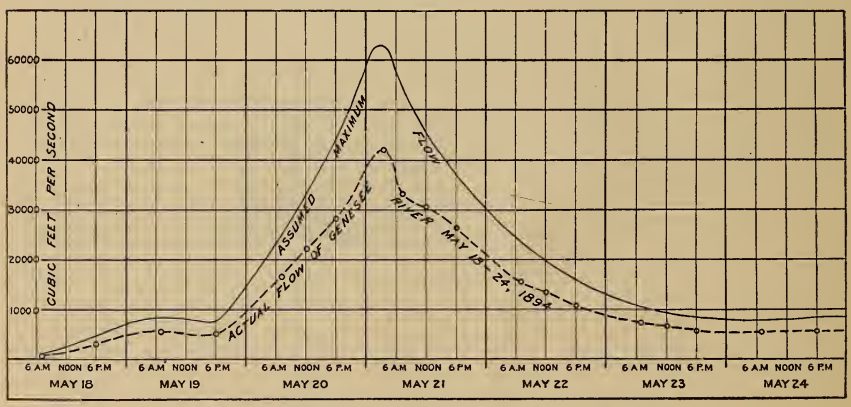


Fig. 3.—Flood flow of Genesee River, May 18-24, 1894.

A flood flow one and one-half times as great as that of May, 1894, which culminated in a maximum of about 42,000 cubic feet per second at 2.30 a. m. of May 21, gives a maximum of 63,000 cubic feet per second, the movement of which would be, under the assumptions, substantially as in the upper curve of fig. 3. As to the probability of a maximum flood flow of 63,000 cubic feet per second on the upper Genesee drainage area, the case of the neighboring Chemung River may be cited, where a flood flow of 67.1 cubic feet per second per square mile occurred in June, 1889. This figure applied to the upper Genesee would give a possible maximum run-off of 71,126 cubic feet per second.

Geologically, the drainage area of Genesee River above Mount Morris, the point of measurement, lies in the shales, sandstones, etc., of the Portage and Chemung groups. Its extreme head waters south

of the Pennsylvania line issue from the lower Carboniferous. Generally the soils throughout the whole basin are heavy and tenacious, inclining to clay. Their capacity for absorbing and retaining water must, therefore, be considered as small.

DISCHARGE MEASUREMENTS OF HEMLOCK LAKE.

Measurements of the run-off of the Hemlock Lake drainage area for the water years 1880 to 1884, inclusive, were made by the Rochester Waterworks. Hemlock Lake lies at an elevation of 896 feet above tide, and has a length of 6.5 miles, with an average width of about 0.5 of a mile. The area of the surface at low water is 1,828 acres. The total drainage basin, including the area of the lake, is 27,554 acres, or about 43 square miles. The shores are bold, and on the east side rise to a height of several hundred feet above the lake in a distance of 2 or 3 miles. At the head of the lake there is a swamp of 118 acres, partially covered at high water.

The outflow of the lake during the period covered by the measurements included in the following table may be considered as having taken place at three points: (1) At the natural outlet of the lake; (2) at an artificial channel through which water was discharged at will for the benefit of the millers on the outlet; and (3) through the conduit of the Rochester waterworks. The run-offs given are the sums of these several outgoes. In order to determine the outflow of the natural outlet, a weir was constructed and the discharge observed at different heights of the lake surface. The discharge into the artificial channel was through submerged orifices of known dimensions, and has been computed from standard formulæ for the discharge of such orifices, the size of the openings and the difference of level of water surfaces above and below being known.

The discharge of the conduit of the Rochester waterworks is as computed from standard formulæ for discharge through pipes. Measurements made by the author and others during the last few years show that the computed quantities passing through the conduit were not far from correct. As a whole, it is believed that the Hemlock Lake results are accurate within from 5 to 8 per cent.

Water drawn from Hemlock Lake for the water years 1880 to 1884, inclusive.

[In inches on the watershed.]

Month.	1880.					1881.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	−1.67	1.26	0.16	.....	a 31.4	−1.33	0.72	0.49	.....	27.3
January	−0.91	1.37	0.15	.....	a 25.5	−1.47	2.24	0.44	.....	24.7
February	−0.11	1.45	0.16	.....	a 27.3	−0.11	1.08	0.54	.....	29.7
March	+0.21	1.47	0.15	.....	a 31.8	+1.20	1.92	1.73	.....	39.1
April	+0.79	1.25	0.15	.....	a 45.7	+1.47	0.52	1.24	.....	45.2
May	+0.87	2.08	0.17	.....	71.8	+1.32	2.23	1.11	.....	69.7
	−0.14	*8.88*	*0.94*	*7.94*	*38.9*	*+0.18*	*8.71*	*5.55*	*3.16*	*39 3*
June	+0.45	1.66	0.36	.....	76.5	+1.08	3.13	0.76	.....	73.9
July	−0.15	1.93	0.41	.....	77.1	+0.58	3.71	0.43	.....	75.6
August	−0.70	3.46	0.35	.....	74.4	.....	0.95	0.50	.....	80.0
	−0.13	*7.05*	*1.12*	*5.93*	*76.0*	*+0.55*	*7.79*	*1.69*	*6.10*	*76.5*
September	−1.13	1.35	0.31	.....	69.7	−0.69	1.73	0.35	.....	77.9
October	−1.57	3.85	0.31	.....	53.4	−0.81	4.23	0.33	.....	59.1
November	−1.24	0.86	0.39	.....	37.1	−0.71	1.81	0.46	.....	44.8
	−1.31	*6.06*	*1.01*	*5.05*	*53.4*	*−0.74*	*7.77*	*1.14*	*6.63*	*60.6*
Year	−0.43	21.99	3.07	18.92	51.8	+0.04	24.27	8.38	15.89	53.9

a Interpolated from average of fifteen years.

Month.	1882.					1883.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	−0.05	4.02	0.66	.....	39.8	−1.51	0.91	0.19	.....	31.0
January	+1.63	1.03	2.04	.....	29.4	−1.56	0.84	0.21	.....	25.7
February	+1.39	1.07	1.40	.....	37.0	+0.03	3.11	0.28	.....	30.6
March	+1.67	1.47	2.82	.....	38.7	+0.95	0.90	0.68	.....	33.3
April	+1.51	2.49	1.53	.....	48.5	+1.57	2.43	1.58	.....	47.8
May	+1.61	5.29	1.74	.....	57.4	+1.59	9.54	2.59	.....	59.1
	+1.29	*15.37*	*10.19*	*5.18*	*41.8*	*+0.18*	*17.73*	*5.53*	*12.20*	*37.9*
June	+1.45	2.31	1.85	.....	71.9	+1.38	4.52	1.65	.....	74.2
July	+0.81	1.42	0.62	.....	78.0	+1.29	2.13	1.08	.....	75.7
August	+0.15	2.17	0.41	.....	76.8	+0.64	2.86	0.45	.....	73.7
	+0.80	*5.90*	*2.88*	*3.02*	*75.6*	*+1.10*	*9.51*	*3.18*	*6.33*	*74.5*
September	−0.44	1.78	0.43	.....	69.4	+0.25	2.36	0.21	.....	65.1
October	−0.99	1.00	0.65	.....	61.4	+0.07	1.62	0.18	.....	55.7
November	−1.38	1.41	0.36	.....	41.8	+0.17	2.02	0.19	.....	45.1
	−0.94	*4.19*	*1.44*	*2.75*	*57.5*	*+0.16*	*6.00*	*0.58*	*5.42*	*55.3*
Year	+0.61	25.46	14.51	10.95	54.2	+0.41	33.24	9.29	23.95	51.4

Water drawn from Hemlock Lake for the water years 1880 to 1884, etc.—Cont'd.

Month.	1884.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	+0.44	2.01	0.54		34.0
January	+0.46	1.78	1.01		24.7
February	+1.28	2.17	2.70		30.2
March	+1.47	3.18	2.71		30.5
April	+1.56	2.21	1.47		42.7
May	+1.62	3.30	1.69		56.7
	+1.14	*14.65*	*10.12*	*4.53*	*36.5*
June	+1.01	2.44	0.75		70.4
July	+0.58	3.98	0.37		68.4
August	+0.27	1.08	0.24		70.8
	+0.62	*7.50*	*1.36*	*6.14*	*69.9*
September	−0.26	2.24	0.71		66.9
October	−0.70	1.34	0.20		52.3
November	−1.17	1.01	0.18		38.9
	−0.71	*4.59*	*1.09*	*3.50*	*52.7*
Year	+0.55	26.74	12.57	14.17	48.9

The drainage area of Hemlock Lake is, as stated, 27,554 acres, and the area of the lake itself at the elevation ±0.0 is 1,828 acres; hence the lake surface is 6.6 per cent of the total drainage area, or the drainage area is 15.1 times the area of the lake surface. On this basis 1 inch on the whole area is 15.1 inches on the lake. Taking into account these statements, it is clear that the data of the table give approximately the natural run-off, although for exact figures corrections for actual elevations of lake surface at the beginning, as well as at the end of each year, should be applied. On this point see the discussion on the minimum flow of Hemlock Lake, on pages 92 and 93. Geologically, the Hemlock Lake Basin proper is in the Hamilton and Marcellus shale, with the hills at the side rising into the rocks of the Portage group.

DISCHARGE MEASUREMENTS OF SKANEATELES LAKE.

The measurements of the run-off of Skaneateles Lake drainage area, as given in the following table, have been made by the Syracuse waterworks over a dam at the foot of the lake or over a weir a short distance below since October, 1890. Previous to 1886 this lake was the principal feeder of the Jordan level of Erie Canal, but in that year Otisco and Owasco lakes were also made feeders. The Skaneateles Lake dam was reconstructed 9 feet high by the State in 1887, and in 1893 was again rebuilt by the Syracuse water board with its spillway 2 feet higher than the crest of the old dam. The area of the water surface of Skaneateles Lake is 12.75 square miles, and the area of the watershed, including the area of the lake, is 73 square miles.

The elevation above tide is 867 feet. The lake lies in a deep valley, with bold shores rising several hundred feet at either side. The figures given in the following table do not represent in any degree the natural run-off of this drainage area, but merely the water yield during the years indicated, in which there was large storage.

In March, 1895, the city of Syracuse began to draw water through its new conduit to Skaneateles Lake. Since that time the results given in the table are the quantity flowing in the outlet as measured on the weir located at Willow Glen plus the outflow through the conduit. Previous to March, 1895, the results are from measurements at the dam at the foot of the lake. The earlier results are possibly affected by errors of from 12 to 15 per cent, while the latter are probably accurate within from 2 to 5 per cent. Geologically the drainage basin of Skaneateles Lake is in the Hamilton group of rocks.

Water drawn from and monthly elevatians of Skaneateles Lake for the months indicated for the water years 1890 to 1897, inclusive.

[Water drawn in inches on the watershed.]

Year, etc.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Total.
1890:													
Mean lake surface	−1.92	−2.08	−2.25	+0.33	+0.33	+0.25	+0.37	+0.50	−0.42	−1.33	−1.08	−1.16	----
Water drawn	------	------	------	------	------	------	------	------	------	------	1.59	1.67	-----
1891:													
Mean lake surface	−1.00	−1.50	−1.00	+0.16	+0.50	0.0	−0.75	−1.42	−2.21	−3.25	−4.12	−5.25	-----
Water drawn	1.62	1.63	1.52	2.42	2.57	a1.90	1.23	1.33	1.93	1.79	1.61	1.21	20.76
1892:													
Mean lake surface	−5.79	−5.50	------	−5.0	−3.67	−1.83	−0.67	−0.33	−0.67	−1.08	−1.83	−2.58	-----
Water drawn	------	------	------	------	------	------	------	------	------	1.35	1.24	1.13	-----
1893:													
Mean lake surface	−2.56	−2.71	−2.92	−2.75	−1.33	0.0	+0.33	−0.67	−1.42	−2.17	−3.00	−3.83	-----
Water drawn	1.09	0.87	0.87	1.10	1.18	3.06	2.10	1.98	1.53	1.08	1.58	1.58	20.02
1894:													
Mean lake surface	−4.75	−4.48	------	------	------	−2.50	−1.27	+0.25	−0.06	−0.88	−1.00	−1.21	-----
Water drawn	1.38	0.86	------	------	------	0.26	0.15	0.57	1.07	1.39	1.46	1.44	-----
1895:													
Mean lake surface	−1.58	−1.20	−1.75	−0.37	−0.17	+0.14	−0.40	−0.92	−1.67	−2.18	−3.12	−4.14	-----
Water drawn	0.32	0.24	0.22	1.29	2.55	2.14	1.64	1.77	1.87	1.64	1.85	1.75	17.28
1896:													
Mean lake surface	−4.56	−4.33	−4.60	−4.08	−2.42	−1.35	−1 58	−1.94	−2.23	−2.94	−3.42	−3.85	-----
Water drawn	1.58	1.51	1.46	1.61	1.50	1.59	1.61	1.51	1.50	1.51	1.50	1.38	18.26
1897:													
Mean lake surface	−3.92	−4.12	−4.29	−4.56	−3.46	−2.67	−2.50	−2.65	------	------	------	------	-----
Water drawn	1.35	1.25	1.08	1.06	0.26	1.12	1.34	1.45	2.21	1.41	1.61	1.47	15.61

a Interpolated. No record. Mean of preceding and following months used.

DISCHARGE MEASUREMENTS OF HUDSON RIVER.

Measurements of the flow of Hudson River have been made over the dam of the Duncan Company, at Mechanicville. In 1887 this company began daily measurement of the amount of water flowing in Hudson River at their mill.[1] With the exception of one or two days this record has been kept for every working day since October 1, 1887. A record has also been kept of the number, size, and kind of turbine water wheel in use for the same period. The Duncan Company placed all this material at the disposal of the survey of the Upper Hudson Valley, of which the author has had charge, thus enabling him to compute the mean daily flow of the river for each working day from October 1, 1887, to November 30, 1896. The flow of Sundays and holidays, when no observations were taken, has been assumed as a mean between the preceding Saturday and the following Monday, etc. The dam is a substantial structure of masonry 16 feet high, with a length of 794 feet between the abutments. The crest is stated by John R. Kaley, the constructing engineer, to be perfectly level, and from all that can be learned it appears that the daily observations have been taken with such care as to leave no reason for doubting that this is a fairly accurate exhibit of the daily flow of the stream for the period covered. This record is therefore considered to be accurate within from 5 to 8 per cent.

The greatest depth on this dam in the nine-year period, 1888 to 1896, inclusive, occurred May 5, 1893, when the gage showed a depth of 7.83 feet and the mean flow of the day was over 53,000 cubic feet per second. The drainage area of Hudson River above the Mechanicville dam is taken at 4,500 square miles.

Experience in flows over dams of this length and with depths as great as from 7 to 8 feet is as yet rather limited in this country, and the question was raised as to the best method of computing the discharge for a case like the one under discussion. The engineers of the British Government in India have had, in connection with their large irrigation works, perhaps more experience in this class of measurement than all others combined, and the formulæ used by them appear more rational in form than those commonly used in the United States for such computations, and after some study it was decided to use these. As many American engineers may not be familiar with these formulæ they are here reproduced. They take the following form:

$$Q = \tfrac{2}{3} L C \sqrt{2 g d^3}, \qquad (1)$$

in which—

Q = the discharge over a thin-edged clear overfall, in cubic feet per second,

L = the length of the dam in linear feet,

[1] Annual Report of the State Engineer and Surveyor of New York, 1895, p. 104.

C = coefficient depending for its value on d,
g = acceleration of gravity = 32.2,
d = depth on crest, in linear feet.

Equation (1) may also take the form—

$$Q = 5.35\ L\ C\ \sqrt{d^3}. \tag{2}$$

To find C for different values of d, we have—

$$C = 1 - \left(\frac{0.04\ (34.6 + d)}{4}\right). \tag{3}$$

This gives a series of values of C corresponding to d. For instance, for $d = 0.25$ foot, $C = 0.651$; for $d = 0.50$ foot, $C = 0.649$, and so on.

For a wide-crested dam the coefficient is further modified to suit the actual width of the crest. For this we have given the expression—

$$C' = C - \left(\frac{0.025\ C\ (B + 1)}{1 + d}\right), \tag{4}$$

in which—

B = the width of the crest in linear feet;
C = the coefficient for a thin-edged weir, corresponding to a depth d, as per equation (3), and
C′ = the adjusted coefficient corresponding to a given breadth B and a depth d.[1]

In the case of the Mechanicville dam we have a stone crest 7 feet in width and slightly inclined upstream. The width of the river a short distance above the dam is considerably over 800 feet; the depth for some distance back is from 16 to 20 feet. In order to avoid a correction for velocity of approach, a crest was assumed 5 feet wide and values of C′ were computed on that basis.

Having obtained values of C′ for $d = 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75$ feet, and so on up to 8 feet, corresponding values of Q were computed and plotted at a large scale as a curve with values of d as abscissas and the corresponding flows as ordinates. From this curve intermediate values of Q have been read off.

[1] The method of deducing equations (3) and (4) may be found in Mullin's Irrigation Manual, 1890, pp. 11, 12, 138, 139, 171, 172.

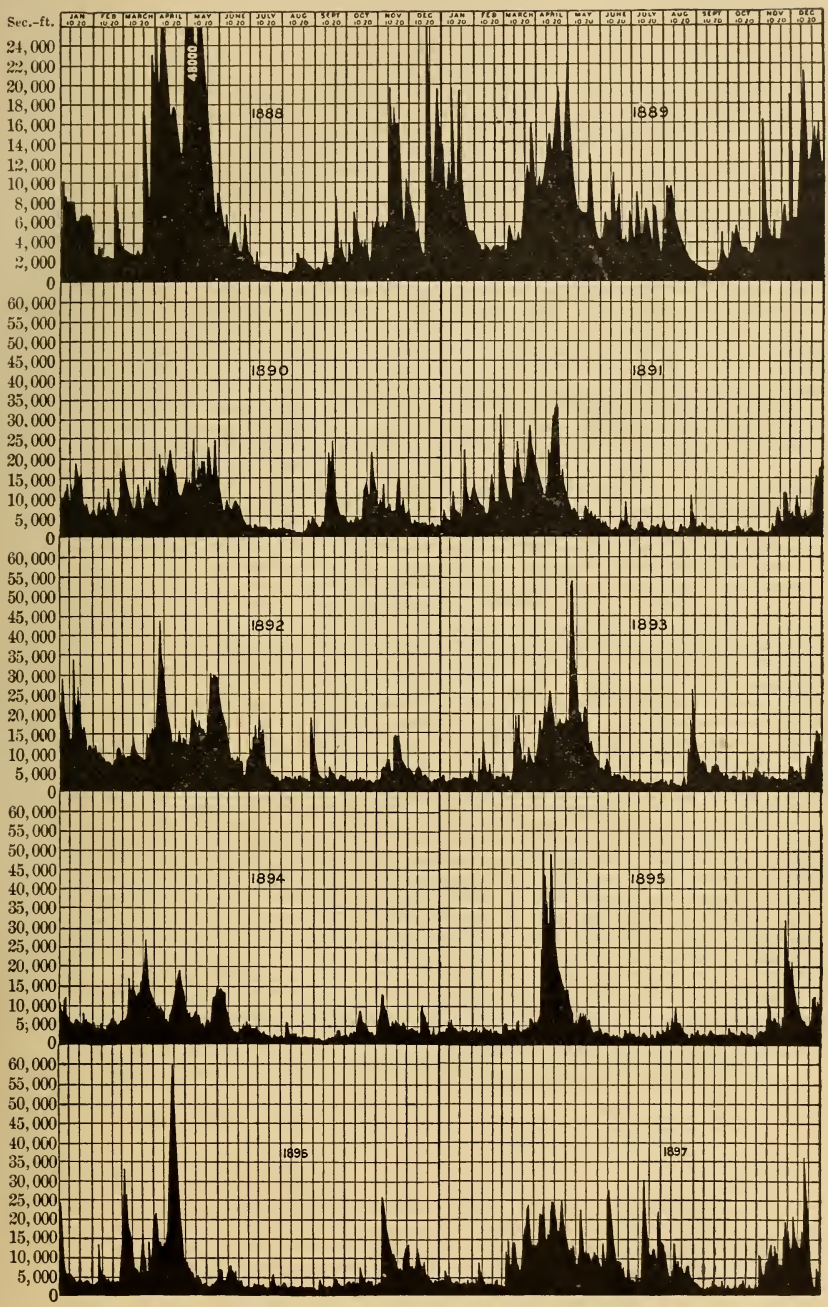


FIG. 4.—Discharge of Hudson River at Mechanicville, New York, 1888 to 1897.

Run-off of Hudson River at Mechanicville from October, 1887, to November, 1896, inclusive.(a)

[In cubic feet per second.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.
December		8,018	10,014	13,226	3,244	8,577	4,031	7,217	4,367	10,899
January		6,367	10,983	11,272	8,284	18,857	3,192	6,757	3,876	6,787
February		3,714	3,790	7,913	11,664	9,263	4,805	4,836	3,543	4,668
March		6,845	8,280	11,129	17,736	10,929	8,250	14,738	4,204	13,600
April		21,200	13,690	15,053	20,021	21,554	17,889	11,135	23,822	24,972
May		21,420	8,871	17,931	5,533	19,622	22,285	7,566	6,850	4,610
Mean		*11,289*	*9,337*	*12,831*	*11,021*	*14,831*	*10,114*	*8,759*	*7,759*	*10,921*
June		4,917	6,869	7,392	3,200	12,395	4,801	7,097	2,816	4,738
July		1,537	5,727	1,950	2,337	9,287	2,521	3,168	2,559	2,772
August		1,725	4,272	2,019	2,666	5,485	5,005	2,456	3,901	2,442
Mean		*2,703*	*5,718*	*3,748*	*2,957*	*9,019*	*4,102*	*4,209*	*3,095*	*3,317*
September		2,851	1,963	8,844	2,040	4,448	6,870	1,889	2,629	2,879
October	2,365	4,608	3,740	9,215	1,472	2,819	3,865	3,649	2,631	4,106
November	4,190	10,642	7,888	9,121	4,088	7,604	3,639	6,379	8,421	11,352
Mean		*6,018*	*4,522*	*9,061*	*2,521*	*4,934*	*4,781*	*3,969*	*4,539*	*6,112*
Yearly mean		7,820	7,197	9,597	6,867	10,909	7,271	6,418	5,780	7,818

[In inches on the watershed.]

December		2.05	2.57	3.39	0.83	2.27	1.03	1.85	1.12	2.79
January		1.62	2.81	2.89	2.12	4.83	0.82	1.73	0.99	1.74
February		0.89	0.88	1.83	2.70	2.22	1.09	1.12	0.82	1.12
March		1.75	2.12	2.85	4.55	2.80	2.11	3.78	1.08	3.49
April		5.26	3.39	3.73	4.97	5.35	4.44	2.76	5.91	6.20
May		5.49	2.27	4.59	1.42	5.03	5.71	1.94	1.76	1.18
Total		*17.06*	*14.04*	*19.28*	*16.59*	*22.50*	*15.20*	*13.18*	*11.63*	*16.52*
June		1.22	1.70	1.83	0.79	3.08	1.19	1.76	0.70	1.18
July		0.39	1.47	0.50	0.60	2.38	0.65	0.81	0.66	0.72
August		0.44	1.09	0.52	0.68	1.41	1.28	0.63	1.00	0.63
Total		*2.05*	*4.26*	*2.85*	*2.07*	*6.87*	*3.12*	*3.20*	*2.36*	*2.53*
September		0.71	0.49	2.19	0.51	1.10	1.70	0.47	0.65	0.71
October	0.61	1.18	0.96	2.36	0.38	0.72	0.99	0.94	0.69	1.05
November	1.04	2.64	1.96	2.26	1.01	1.89	0.90	1.58	2.08	2.82
Total		*4.53*	*3.41*	*6.81*	*1.90*	*3.71*	*3.59*	*2.99*	*3.42*	*4.58*
Yearly total		23.64	21.71	28.56	20.56	33.08	21.90	19.37	17.46	23.63

a Annual Report of the State Engineer and Surveyor of New York, 1895, pp. 107, 120.

DISCHARGE MEASUREMENTS OF CROTON RIVER.

The record of the run-off of Croton River as measured at the old Croton dam for the water years 1870 to 1896, inclusive, is given in the table on pages 83 to 85. The watershed of the Croton consists of a broken, hilly country with its surface soil composed principally of sand and gravel. Clay, hardpan, and peat, while found in a few localities, are for the whole area only present to a limited extent. The rock formation consists generally of gneiss, although strata of limestone, some micaceous and talcose slates, with veins of granite, serpentine, and

iron ore, occur in a few places. The drainage area lies almost entirely in the State of New York, only a small portion being in Connecticut. It amounts to about 338 square miles above the old Croton dam and to 360 square miles above the new Croton dam under construction. The main river is formed by three branches, known, respectively, as East, Middle, and West branches, which, rising in the southern part of Dutchess County, flow south through Putnam County and unite near its south boundary. The river then flows across Westchester County to Hudson River, into which it empties at Croton Point, about 30 miles north of the city of New York. The principal tributaries aside from East, Middle, and West branches are Kisko, Titicus, Cross, and Muscoot rivers. The monthly and annual rainfall of the Croton watershed, as well as the run-off of the water years, from 1870 to 1896, inclusive, are given in the following table. The average annual rainfall for this period was 48.10 inches and the run-off 24.65 inches.[1]

Rainfall and run-off of Croton River drainage area from 1870 to 1896, inclusive.

[In inches on the watershed.]

Month.	1870.		1871.		1872.		1873.		1874.		1875.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	5.96	3.07	1.49	0.64	2.59	2.11	3.68	1.45	4.13	3.38	1.78	0.98
January	4.51	3.99	3.80	0.59	1.44	2.08	5.66	4.29	6.96	8.22	2.74	0.65
February	6.40	4.28	3.81	2.21	1.22	1.25	3.09	1.72	2.78	2.79	3.47	4.09
March	3.80	3.56	4.27	3.52	2.59	1.75	3.08	4.03	1.57	3.03	4.99	3.24
April	5.45	4.11	3.01	2.02	3.04	3.11	3.77	7.12	6.31	3.63	3.04	5.58
May	2.30	1.86	3.45	2.06	3.69	1.29	2.91	2.19	1.99	3.19	1.08	1.86
	28.42	*20.87*	*19.83*	*11.04*	*14.57*	*11.59*	*22.19*	*20.80*	*23.74*	*24.24*	*17.10*	*16.40*
June	2.06	0.83	5.73	1.43	4.00	1.22	0.71	0.54	3.57	0.92	3.02	0.59
July	3.43	0.51	5.07	0.73	4.34	0.61	2.21	0.49	5.98	1.43	3.10	0.58
August	5.10	0.51	5.24	0.85	5.99	1.64	5.73	0.71	2.75	0.89	10.33	5.80
	10.59	*1.85*	*16.04*	*3.01*	*14.33*	*3.47*	*8.65*	*1.74*	*12.30*	*3.24*	*16.45*	*6.97*
September	2.85	0.35	1.44	0.63	3.69	1.25	3.73	0.52	3.56	0.58	2.11	0.90
October	4.73	0.42	6.18	1.92	2.15	1.13	5.13	1.45	2.40	0.81	3.61	0.85
November	2.51	0.62	4.35	3.41	4.91	2.67	3.72	1.81	2.72	0.74	4.61	2.05
	10.09	*1.39*	*11.97*	*5.96*	*10.75*	*5.05*	*12.58*	*3.78*	*8.68*	*2.13*	*10.33*	*3.80*
Total	49.10	24.11	47.84	20.01	39.65	20.11	43.42	26.32	44.72	29.61	43.88	27.17

1 See Wegmam's History of the Water Supply of the City of New York, Chap. IX, The Croton watershed.

Rainfall and run-off of Croton River drainage area from 1870 to 1896, etc.—Cont'd.

Month.	1876.		1877.		1878.		1879.		1880.		1881.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	1.56	1.84	2.35	1.19	1.52	1.97	8.74	7.23	4.26	2.03	2.49	0.54
January	1.42	1.59	2.68	0.84	4.49	2,85	2.52	1.45	4.00	2.75	4.19	0.76
February	4.91	3.65	0.80	1.55	3.65	3.92	2.85	2.77	2.92	2.99	5.28	4.32
March	6.33	7.16	7.66	6.97	3.10	3.89	4.96	4.30	4.51	3.01	6.14	6.09
April	4.43	6.39	2.35	3.02	2.85	1.69	5.10	5.12	3.99	2.09	1.67	1.88
May	3.99	2.03	0.85	0.89	4.97	1.57	2.45	1.77	1.17	0.98	3.74	1.39
	22.64	*22.66*	*16.69*	*14.46*	*20.58*	*15.89*	*26.62*	*22.64*	*20.85*	*13.85*	*23.51*	*14.98*
June	2.52	0.71	4.95	0.62	4.65	1.52	5.29	0.94	1.28	0.52	5.72	1.67
July	3.42	0.55	4.65	0.51	4.28	0.74	5.95	0.73	5.65	0.54	2.45	0.58
August	1.20	0.50	2.54	0.49	2.66	0.68	5.83	1.48	3.60	0.52	1.71	0.52
	7.14	*1.76*	*12.14*	*1.62*	*11.59*	*2.94*	*17.07*	*3.15*	*10.53*	*1.58*	*9.88*	*2.77*
September	5.21	0.37	1.49	0.34	6.61	2.13	3.43	1.09	2.69	0.50	0.75	0.51
October	1.50	0.38	8.38	1.14	3.78	0.93	0.95	0.67	3.25	0.51	3.65	0.52
November	3.40	0.71	8.16	4.18	4.36	2.09	2.49	0.82	2.97	0.57	4.50	0.48
	10.11	*1.46*	*18.03*	*5.66*	*14.75*	*5.15*	*6.87*	*2.58*	*8.91*	*1.58*	*8.90*	*1.51*
Total	39.89	25.88	46.86	21.74	46.92	23.98	50.56	28.37	40.29	17.01	42.29	19.26

Month.	1882.		1883.		1884.		1885.		1886.		1887.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	6.53	1.73	2.68	1.29	3.45	0.64	7.34	3.78	3.84	2.09	4.29	1.19
January	4.41	2.40	2.80	1.06	5.07	2.14	5.59	4.12	5.24	3.42	5.68	2.74
February	5.96	4.23	5.21	3.81	6.31	4.95	4.66	2.44	5.20	4.89	6.01	4.98
March	4.58	4.74	1.67	3.03	4.82	5.01	1.29	2.05	3.86	2.50	3.60	3.69
April	1.36	1.43	3.94	2.73	2.96	3.00	2.09	2.62	3.61	4.51	3.47	3.26
May	6.30	2.20	2.86	1.38	4.33	1.91	2.44	1.58	4.54	2.15	0.32	1.30
	29.14	*16.73*	*19.16*	*13.30*	*26.94*	*17.65*	*23.41*	*16.59*	*26.29*	*19.56*	*23.37*	*17.16*
June	3.04	1.70	5.64	0.63	2.04	0.70	1.19	0.59	3.09	0.78	7.70	1.16
July	3.63	0.69	4.26	0.52	6.54	0.81	5.27	0.52	4.40	0.61	13.32	2.63
August	3.92	0.52	2.09	0.52	4.50	1.18	7.35	0.58	3.21	0.58	7.06	3.56
	10.59	*2.91*	*11.99*	*1.67*	*13.08*	*2.69*	*13.81*	*1.69*	*10.71*	*1.97*	*28.08*	*7.35*
September	14.33	3.25	2.45	0.51	1.69	0.74	1.09	0.42	2.30	0.51	2.00	0.90
October	3.33	2.27	6.99	0.66	3.74	0.57	5.19	0.55	2.28	0.52	3.12	1.03
November	1.66	0.96	1.79	0.69	4.37	0.98	5.99	2.19	5.57	0.88	2.69	0.95
	19.32	*6.48*	*11.23*	*1.86*	*9.80*	*2.29*	*12.27*	*3.16*	*10.15*	*1.91*	*7.81*	*2.88*
Total	59.05	26.12	42.38	16.83	49.82	22.63	49.49	21.44	47.15	23.44	59.26	27.39

Rainfall and run-off of Croton River drainage area from 1870 to 1896, etc.—Cont'd.

Month.	1888.		1889.		1890.		1891.		1892.		1893.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	6.71	2.48	6.13	5.26	2.94	4.55	3.71	1.65	5.65	1.64	1.11	1.48
January	5.56	4.01	5.14	4.41	2.03	2.34	9.76	6.84	5.95	5.07	3.29	1.70
February	5.07	4.95	2.33	2.36	4.94	3.19	6.02	5.73	1.22	1.54	4.60	3.27
March	6.44	4.69	1.86	2.10	5.66	4.72	3.36	4.37	2.90	2.10	4.52	7.21
April	2.68	4.85	4.42	2.58	3.03	3.29	3.77	2.90	1.08	1.42	3.55	3.57
May	6.27	2.67	3.22	1.76	5.74	2.73	1.36	0.89	5.74	1.62	8.18	6.06
	32.73	*23.65*	*23.10*	*18.47*	*24.34*	*20.82*	*27.98*	*22.38*	*22.54*	*13.39*	*25.25*	*23.29*
June	2.00	1.39	4.51	1.43	3.56	1.53	1.81	0.63	3.84	1.15	2.43	0.96
July	2.43	0.67	7.74	1.63	5.46	0.71	2.97	0.40	5.05	0.70	2.38	0.40
August	6.87	1.11	2.90	4.03	4.70	0.59	5.61	0.31	6.12	0.90	7.06	0.72
	11.30	*3.17*	*15.15*	*7.09*	*13.72*	*2.83*	*10.39*	*1.34*	*15.01*	*2.75*	*11.87*	*2.08*
September	10.77	3.11	6.13	2.27	6.86	2.04	1.87	0.38	2.65	0.51	2.65	0.53
October	4.80	2.58	4.85	1.93	7.63	3.36	2.15	0.41	0.92	0.17	6.42	1.17
November	4.49	3.04	8.45	5.29	1.12	2.09	3.86	0.64	7.85	1.58	3.32	2.08
	20.06	*8.73*	*19.43*	*9.49*	*15.61*	*7.49*	*7.88*	*1.43*	*11.42*	*2.26*	*12.39*	*3.78*
Total	64.09	35.55	57.68	35.05	53.67	31.14	46.25	25.15	48.97	18.40	49.51	29.15

Month.	1894.		1895.		1896.		Mean.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	5.34	4.12	4.43	2.57	4.88	1.30		
January	3.40	1.77	3.63	3.42	1.52	2.06		
February	5.01	2.15	3.34	1.04	6.65	4.33		
March	1.62	5.21	1.88	3.87	8.20	7.90		
April	3.07	2.44	5.63	4.22	0.96	3.05		
May	6.67	1.88	2.41	1.33	3.09	0.87		
	25.11	*17.57*	*21.32*	*16.45*	*25.30*	*19.51*	*23.44*	*18.00*
June	1.69	1.48	1.89	0.49	3.79	0.97		
July	1.75	0.45	3.95	0.44	3.98	0.86		
August	1.45	0.71	3.10	0.62	4.56	0.76		
	4.89	*2.64*	*8.94*	*1.55*	*12.33*	*2.59*	*12.54*	*2.90*
September	7.49	0.57	1.16	0.09	6.50	0.65		
October	5.94	0.75	3.55	0.40	2.17	0.88		
November	4.44	3.37	2.91	0.82	3.96	1.73		
	17.87	*4.69*	*7.62*	*1.31*	*12.63*	*3.26*	*12.12*	*3.14*
Total	47.87	24.90	37.88	19.31	50.26	25.36	48.10	24.65

The run-off as given is stated by A. Fteley, chief engineer of new Croton aqueduct, to have been corrected as far as necessary for the storage, and accordingly represents approximately the natural run-off of the stream.

Evaporation from the Croton River watershed as given by differences between rainfall and run-off in preceding table.

[Inches on watershed.]

Year.	December to May.	June to August.	September to November.	Total.	Year.	December to May.	June to August.	September to November.	Total.
1870	7.55	8.74	8.70	24.99	1885	6.82	12.12	9.11	28.05
1871	8.79	13.03	6.01	27.83	1886	6.73	8.74	8.24	23.71
1872	2.98	10.86	5.70	19.54	1887	6.21	20.73	4.93	31.87
1873	1.39	6.91	8.80	17.10	1888	9.08	8.13	11.33	28.54
1874	*a* 0.50	9.06	6.55	15.11	1889	4.63	8.06	9.94	22.63
1875	0.70	9.48	6.53	16.71	1890	3.52	10.89	8.12	22.53
1876	*a* 0.02	5.38	8.65	14.01	1891	5.60	9.05	6.45	21.10
1877	2.23	10.52	12.37	25.12	1892	9.15	12.26	9.16	30.57
1878	4.69	8.65	9.60	22.94	1893	1.90	9.79	8.61	20.36
1879	3.98	13.92	4.29	22.19	1894	7.54	2.25	13.18	22.97
1880	7.00	8.95	7.33	23.28	1895	4.87	7.39	6.31	18.57
1881	8.53	7.11	7.39	23.03	1896	5.79	9.74	9.37	24.90
1882	12.41	7.68	12.84	32.93	Mean	5.44	9.64	8.38	23.46
1883	5.86	10.32	9.37	25.55					
1884	9.29	10.39	7.51	27.19					

a During this period the run-off exceeded rainfall.

This stream is an exceedingly good water yielder. The minimum yield for a complete water year for the whole period from 1870 to 1896 was in 1883, in which water year, from December to November, inclusive, the total run-off was 16.83 inches.

The Croton watershed contains 31 lakes and ponds, many of which have been utilized as natural storage basins by constructing dams at their outlets. The following tabulation gives the entire natural and artificial storage, either actually carried out or now under construction, in the Croton watershed:

Storage capacity in the Croton watershed.

	U. S. gallons.
Boyds Corners reservoir	2,727,000,000
Middle Branch reservoir	4,004,000,000
Lake Mahopac *a*	575,000,000
Lake Kirk *a*	565,000,000
Lake Glenida *a*	165,000,000
Lake Gilead *a*	380,000,000
Lake Waccabuc *a*	200,000,000
Lake Tonnetta *a*	50,000,000
Barretts Pond *a*	170,000,000
China Pond *a*	105,000,000
White Pond *a*	100,000,000
Pine Pond *a*	75,000,000
Long Pond *a*	60,000,000

a The lakes and ponds marked thus are owned by the city. Those not marked are city reservoirs.

Storage capacity in the Croton watershed—Continued.

	U. S. gallons.
Peach Pond *a*	230,000,000
Cross Pond *a*	110,000,000
Haines Pond *a*	25,000,000
East Branch reservoir	9,028,000,000
Titticus reservoir	7,000,000,000
Caramel reservoir	9,000,000,000
New Croton reservoir	32,000,000,000
Amawalk reservoir	7,000,000,000
Total storage	73,569,000,000

a The lakes and ponds marked thus are owned by the city. Those not marked are city reservoirs.

The drainage area above the new Croton dam now constructing is 360 square miles. It is considered by the Croton aqueduct officials that the storage afforded by this reservoir system will furnish a daily supply of at least 280,000,000 gallons. At this rate the utilization from this drainage area of 360 square miles will become 778,000 gallons per square mile per day, or 1.20 cubic feet per square mile per second.

MAXIMUM AND MINIMUM FLOW OF STREAMS IN NEW YORK.

The data relating to floods in Genesee River, given on pages 72 to 74, as well as the following facts, may be taken as indicating some of the maximum flows of streams in New York.

FLOODS IN CHEMUNG RIVER.

Severe floods have occurred in this stream several times during the historical period, the most severe being the great flood of June, 1889, which caused serious damage to property at Elmira and Corning. Chemung River is formed by the junction of Tioga and Cohocton rivers at Painted Post, a few miles above Corning, the principal tributary of the Tioga in this State being the Canisteo. Tioga River rises near Blossburg, in Tioga County, Pennsylvania, in an elevated region from 1,500 to 2,500 feet above tide. The descent from the extreme head waters near the Fall Brook Coal Company's mines to Blossburg is at the rate of about 22 feet per mile, after which it descends at the rate of about 11 feet to the mile. The streams tributary to the Tioga are also very rapid; they flow mainly through deep, narrow rock valleys, with their heads generally at an elevation of nearly 2,000 feet above tide. Recently the hill slopes have been largely denuded of timber, thus permitting a rapid descent of the rainfall or melted snow. Hence it results that Tioga River not only naturally rises quickly, but its freshet flows have very high velocities. Canisteo River, joining the Tioga from the west, has an average slope of about 5.5 feet per mile. The slope of the Chemung from Painted Post to Elmira is

at the rate of 5.9 feet per mile; thence through the city of Elmira for 3 miles at the rate of 3.5 feet per mile; from Elmira to Chemung, 5.5 feet per mile, and thence to Athens, where it joins the main East Branch of the Susquehanna, 3.4 feet per mile. Cohocton River is also a stream of comparatively low slope.

The foregoing facts indicate that the floods will be slower in rising on Canisteo and Cohocton rivers than on the Tioga. In a general storm, where other conditions are equal, the first flood water to reach Corning and Elmira will come from the Tioga, to be followed later by large flows from the Canisteo and the Cohocton. The areas drained by these streams are approximately as follows:

Areas drained by tributaries of Chemung River.

	Square miles.
Tioga, aside from the Canisteo	750
Canisteo	780
Cohocton	425
Chemung above Elmira	100
Total	2,055

On May 31, 1889, the region tributary to Chemung River above Elmira was visited by a phenomenally heavy rainfall, amounting in many places to nearly 10 inches. The center of this downpour was located about 10 miles south and 15 miles west of Elmira. At Elmira the rainfall was not unusual, 1.5 inches being recorded from 8 p. m. of May 31 to 7 a. m. of June 1; but at Wellsboro, 36 miles southwesterly from Elmira, the total precipitation was 9.8 inches, of which 7.45 inches occurred after 9 p. m. of May 31 and before 7 a. m. of June 1. At South Canisteo, 45 miles westerly from Elmira, a total fall of 6.25 inches was recorded, of which 4.5 inches fell between midnight and 3 a. m. of June 1. Farther up the valley 6 inches were measured between the same hours. At Painted Post a total fall of about 8 inches was reported. At Savonia, on the Cohocton, 5 inches fell, but the fall grew gradually less to the north. At a number of points to the south and southwest rainfalls of from 6 to 8 inches were recorded for May 31, heavy rains occurring as far south as Virginia.

It will be noticed from the preceding statement of the rainfall of May 31 and June 1, 1889, that the heaviest precipitation was practically at the same time over the entire watershed. The following indicates the heights of the flood wave at several points: At Tioga the river was highest about 6.30 a. m. on June 1; Canisteo River was at its highest a little before noon of June 1; at Painted Post the local creeks reached their highest points at 5 a. m., and the Tioga began to rise rapidly about the same time; the Chemung reached a height at this place of 18 feet above low water; at Elmira the river began to rise rapidly about 9 a. m. of June 1 and was at its highest at about 7 p. m.

According to Francis Collingwood,[1] who investigated the Chemung River flood of 1889, for the city of Elmira, the foregoing data indicate that in a flood coming more from the south than from the west the highest water in Chemung River may be looked for about twelve hours after the highest water has passed the Tioga, and at a somewhat later period when the water comes more from the Canisteo and Cohocton rivers. Mr. Collingwood concludes that the flood flow at Elmira will usually be not less than fourteen hours after a heavy rain on the head waters of these streams.

The surveys made by Mr. Collingwood, in which a considerable number of flood elevations were fixed and plotted, show that the discharge of Chemung River at its maximum was about 138,000 cubic feet per second, and the mean velocity 12.72 feet per second. A maximum of 138,000 cubic feet per second, gives 67.1 cubic feet per second per square mile. By the way of comparison, it may be noted that a maximum has been recorded on the Croton watershed of 74.87 cubic feet per second per square mile; also that Genesee River at Mount Morris gave in the flood of 1894 the maximum discharge of 42,000 cubic feet per second, or 48.6 cubic feet per second per square mile.

The Chemung flood of 1889 did considerable damage both at Corning and at Elmira, and the investigations of Mr. Collingwood were with reference to plans for protecting the latter city from devastation by future floods. Several plans were proposed, all including the rectification, clearing, and lowering of the river through the city with such dikes at the side as might be necessary for special protection at exposed points. The estimated cost of these various projects varied from $336,000 to $700,000. So far as known, nothing in the way of constructing the work at Elmira has yet been done.

The city of Corning, which is situated on the banks of Chemung River a few miles above Elmira, was also greatly damaged by the flood of June, 1889. In consequence, it was determined to construct protective works, and an act of the legislature was accordingly passed in 1892, creating a board of river commissioners, with authority to issue bonds for this purpose, under which enactment and amendments thereto bonds to the amount of $150,000 have been issued. The work began in June, 1896, and is now about completed. The plan adopted is to construct earthen dikes to confine the river at all points where it is subject to overflow. The total length of the dikes is about 25,800 feet, or 4.9 miles, and they vary in height from 4 to 19 feet. The river dikes were generally 8 feet wide on top, with a slope of from 3 to 1 (3 horizontal to 1 vertical) on the river side, and a slope of 2 to 1 on the land side.

Whatever the purpose for which an inland stream is to be utilized,

[1] Report on the Prevention of Floods at Elmira.

the first question asked by an experienced engineer is with regard to the minimum flow. If for power development, the minimum flow will determine the amount of power which can be insured on a given head; if for the water supply of a town, the minimum flow will indicate at once the number of people which may be supplied without storage. From every point of view, therefore, a knowledge of the minimum flow is a matter of the first importance. Below are given the minimum flows of the inland streams of the State of New York so far as information is at hand.

LOW-WATER FLOW OF OATKA CREEK.

The drainage area of this stream above the point of measurement is 27.5 square miles. The mean flow for the month of August, 1891, was 6 cubic feet per second; for September, 5.83 cubic feet per second; for October, 5.8 cubic feet per second. Expressed in cubic feet per second per square mile, the foregoing results are 0.218 cubic foot for August, 0.212 cubic foot for September, and 0.211 cubic foot for October. Expressed in inches on the watershed, the run-off of this stream for August to October, 1891, was from 0.24 to 0.25 inch per month. For several days during the months of August to October, 1891, the flow of Oatka Creek was down to about 4.2 cubic feet per second, or to about 0.151 cubic foot per square mile per second. On September 26, 1891, the recorded mean flow for the the day was 3.77 cubic feet per second, or 0.137 cubic foot per square mile per second.

As a general proposition, statements of minimum flows of streams ought not to be based on the record of single days, especially on streams where there are mill ponds above the point of measurement, because such accidental circumstances as the holding back of the water may vitiate the result; from this point of view an average extending over as long a period as possible should be taken.

The measurements of Oatka Creek from August to October, 1891, illustrate well the nearly universal tendency of streams to run either at approximately a fixed rate or to decrease only very slowly after the tributary ground water has become well drawn down. For several days at a time the records show only slight variations.

LOW-WATER FLOW OF GENESEE RIVER.

The drainage area above Mount Morris, the first point of measurement, is 1,070 square miles; above Rochester, the second point, 2,365

A. ERIE CANAL AQUEDUCT AND SOUTH SIDE OF MAIN STREET BRIDGE, ROCHESTER

B. GREAT FLOOD OF 1865 AT ROCHESTER, SHOWING LUMBER LODGED AGAINST AQUEDUCT BRIDGE.

square miles. The following table gives the mean monthly flows at Mount Morris and Rochester for several low months of the year 1895:

Mean monthly flow of Genesee River at Mount Morris and Rochester.

Month.	Mount Morris.			Rochester.	
	Mean flow (cubic feet per second).	Cubic feet per second per square mile.	Inches on the water shed.	Mean flow (cubic feet per second.)	Cubic feet per second per square mile.
May	174	0.163	0.19	385	0.380
June	128	0.119	0.13	283	0.226
July	105	0.099	0.11	232	0.165
August	115	0.108	0.12	254	0.169
September	100	0.093	0.10	221	0.106
October	104	0.097	0.11	230	0.093

Comparing the foregoing figures for Mount Morris with those for Rochester for the month of October, 1895, it is seen that the proportion of run-off at Rochester was somewhat less for that month than at Mount Morris, although for the previous months it appears to have been larger. The explanation of this is that there are between Rochester, Mount Morris, and Dansville extensive flats aggregating from 60 to 80 square miles. The temporary ground-water storage of these flats acts to sustain a somewhat more equable flow at Rochester than at Mount Morris, above which point there are proportionately much smaller areas of flats.

The foregoing minimum flows of Genesee River show conclusively that in its present condition it is not a good mill stream. The great variations in run-off are conclusive on this point. The figures show that the run-off of the stream may be exceedingly slack during the summer and fall months.

In the summer of 1846 Daniel Marsh made a series of measurements in order to determine the low-water flow of that year. As the result of 9 measurements made at various times in July and August he placed the minimum flow at Rochester in 1846 at 412 cubic feet per second.

If we examine the meteorological records of western New York for the years 1844 to 1846, we find that the period covered was one of low rainfall. For instance, at Rochester the rainfall for the storage period of the year 1846 (from December, 1845, to May, 1846, inclusive) was only 11.57 inches; the rainfall of the growing period, 11 30 inches; for the replenishing period, 13.16 inches; the total for the water year 1846 being 36.03 inches. For 1845 the total was 34.66 inches. For 1844 the storage period rainfall was 10.52 inches; growing period, 8.23 inches; replenishing period, 7.68 inches; total for the year, 26.43 inches.

At Middlebury Academy, Wyoming County, in the drainage area of Oatka Creek, the rainfall for the water year 1845 was, for the storage period, 12.59 inches; growing period, 4.82 inches; replenishing period, 8.60 inches; total for the year, 26.01 inches. The record for the year 1846 at Middlebury is not given. It is clear, therefore, so far as we have any definite meteorological record, that the measurements made by Mr. Marsh in 1846 were at a time of very low water.

The foregoing statements indicate that apparently the minimum summer flow of Genesee River has decreased from 462 cubic feet per second in 1846 to about 220 cubic feet per second in 1895. As to the reason for this decrease it is believed that the extensive deforestation of the drainage area which has taken place since 1846 offers full explanation. In 1846 the upper Genesee drainage area was still very largely in forest. Probably of the entire area above Rochester the virgin forest was from 65 to 70 per cent of the whole. We have, therefore, apparently a marked case where the deforestation of a large area has materially reduced the minimum run-off.

LOW-WATER FLOW OF HEMLOCK LAKE.

According to a report made by Henry Tracy, the minimum flow of Hemlock Lake (drainage area 43 square miles) is 5 cubic feet per second, or 0.116 cubic foot per square mile per second.[1]

The table on pages 76 and 77 gives, as previously stated, the quantity of water passing out of Hemlock Lake for the period covered and without reference to the natural flow. In order to obtain the approximate natural flow for the year we must take into account the mean elevations of lake surface. Thus, for the water year 1880 the mean elevation of the first month, December, was —1.67, while for the last month, November, it was —1.24. The difference (0.43 foot) represents the gain in depth of storage for the year. Computing for the value of this storage in inches on the drainage basin, we have 0.28 inch, which, added to the quantity of water passing out of the lake (3.07 inches), gives as the approximate total run-off for the year 3.35 inches. Since 1880 was a very dry year, we may compute the flow for the entire water year to be 10.3 cubic feet per second, which again amounts to 0.24 cubic foot per square mile per second. So far as known this is the lowest annual run-off thus far measured in the State of New York.

For the five-year period included in this table, the total rainfall and run-off are as follows:

[1] Report on the cost and policy of constructing reservoirs of Conesus, Hemlock, Honeoye, and Canadice lakes. Senate Document No. 40, 1850.

UPPER FALLS OF GENESEE RIVER AT PORTAGE.

Rainfall and run-off of Hemlock Lake.

Water year.	Rainfall.	Run-off.
	Inches.	*Inches.*
1880	21.99	3.07
1881	24.27	8.38
1882	25.46	14.51
1883	32.24	9.29
1884	26.74	12.57
Add for rise in level	.....	0.40
Total	131.70	48.22

For the five-year period the total run-off was therefore only 36.6 per cent of the rainfall. In 1880 the run-off was only 15.2 per cent of the rainfall.

LOW-WATER FLOW OF MORRIS RUN.

The result of a measurement of Morris Run, a tributary of Oatka Creek, the source of a part of the water supply of the village of Warsaw, Wyoming County, made from July 4 to December 26, 1894, is shown by the accompanying table. The measured drainage area is 156 acres, but it may, by reason of the peculiar topography, be somewhat greater than this. The water issues along the thread of the short valley in the form of springs. The measurement was made by a thin-edged notched weir at a point just below the lowest spring. As may be observed, the flow varied greatly at different times, the minimum being 77,630 gallons per day or 7.2 cubic feet per minute, in October. On July 8 the discharge was 238,580 gallons, or 22.1 cubic feet per minute for twenty-four hours. There is a popular impression that springs do not vary their flow at different seasons. The measurements of Morris Run are valuable, therefore, as illustrating that even a spring-fed stream will gradually decrease during a dry season.

Daily mean discharge in cubic feet per minute of Morris Run near Warsaw, New York, in 1894.

Day.	July.	August.	September.	October.	November.	December.
1	.....	16.0	10.4	.....	10.9	.....
2	.....	17.3	.....	.....	.....	.....
3	.....	16.7	8.3	.....	.....	10.0
4	19.4	18.3	8.0	7.8	.....	.....
5	17.8	.....	7.8	8.2	.....	.....
6	19.5	16.2	.....	.....	9.4	.....
7	20.9	14.9	.....	6.7	.....	.....

Daily mean discharge in cubic feet per minute of Morris Run near Warsaw, New York, in 1894—Continued.

Day.	July.	August.	September.	October.	November.	December.
8	22.1					
9	21.2					
10	21.3					
11	20.8			9.4		21.9
12	20.6			7.8		
13	19.7					16.2
14	20.1					
15	19.7			8.8		14.9
16	19.3		8.8		8.2	
17	18.7		8.2	7.8		
18	18.3		19.0	7.8		13.4
19	17.5			7.2	8.2	
20	17.9					13.6
21	21.2		11.1	7.2	8.2	
22	20.6		8.8		8.8	
23	20.0			7.2		
24	20.4		8.8	53.8	8.2	13.6
25	18.7					
26	17.8			8.8	8.2	13.6
27	17.3			7.8		
28	17.1		8.8			
29	17.8		8.8	7.2		
30	16.3			7.2		
31	16.5	11.7		19.0		

LOW-WATER FLOW OF WEST BRANCH OF CANADAWAY CREEK.

In the summer of 1883 measurements were made of the West Branch of Canadaway Creek in Chautauqua County, from July 18 to September 2 of that year. This stream, which is the source of the water supply of the village of Fredonia, has a drainage area above the point of measurement of 4.3 square miles. The valley is deep cut for a distance of 3 miles from the measuring point to its extreme headwaters. Small springs issue frequently throughout the valley. On July 18, 1883, the stream was flowing at the rate of 541,620 gallons in 24 hours, or 50.2 cubic feet per second, and very gradually decreased to 270,000 gallons, or 25 cubic feet per minute, on July 22. Rains between July 22 and July 29 brought the stream up to a discharge of 1,319,000 gallons per day, or 122.1 cubic feet per minute, on the latter date. The flow then gradually decreased during the month of August until, on August 26, it was only 216,000 gallons per

day, or 20 cubic feet per minute, which was the lowest point reached during the summer of 1883.

This stream can not be considered a good water yielder. A mean discharge of 216,000 gallons in twenty-four hours from a drainage area of 4.3 square miles represents a yield of 0.334 cubic foot per second, or, what is the same thing, 0.078 cubic foot per square mile per second. It is apparent, therefore, that even a spring-fed stream with a deep valley in Chautauqua County may at times furnish a very small outflow, though it should not be overlooked that the flow of 0.078 cubic foot per square mile per second was the extreme minimum for one day only. The relations of this extreme minimum to the daily flows during the period covered by the measurements may be easily gathered from an inspection of the table. The gradual falling in water yield from August 1 to 26 is the most interesting fact revealed by these measurements.

The following was the rainfall at the point of measurements during the month of August, 1883:

	Inches.
August 3	0.04
August 13	0.10
August 20	0.05
August 23	0.05
August 28	1.98

Daily mean discharge in cubic feet per minute of West Branch of Canadaway Creek, near Fredonia, New York.

[Drainage area, 4.3 square miles.]

Day.	July.	August.	September.	Day.	July.	August.	September.
1		56.5	47.6	17		31.7	
2		50.3	45.0	18	50.2	28.4	
3		46.2		19	49.3	29.3	
4		45.4		20	45.7	31.7	
5		39.8		21	44.0	33.2	
6		36.9		22	25.0	22.9	
7		36.0		23		25.6	
8		34.1		24			
9		34.1		25		22.1	
10		33.2		26		20.0	
11		31.7		27		21.3	
12		30.2		28		105.1	
13		30.2		29	122.1	321.9	
14		32.4		30		101.7	
15		27.0		31	62.4	60.0	
16		27.9					

LOW-WATER FLOW OF SKANEATELES LAKE.

So far as can be learned, no definite statements of the minimum flow from this drainage basin, having an area of 73 square miles, have ever been made. Before the taking of the waters of this lake for the supply of the city of Syracuse the supply was ample for the canal, and close estimates were not made. For the run-off of a water year we find by the table on page 78 that 1897 was the lowest thus far measured, the total of that year being 15.61 inches on the watershed. The indications of the table, so far as they go, are that the Skaneateles area is a good water yielder. Nevertheless, it is improbable that 1897 was a year of minimum flow.

LOW-WATER FLOW OF OSWEGO RIVER.

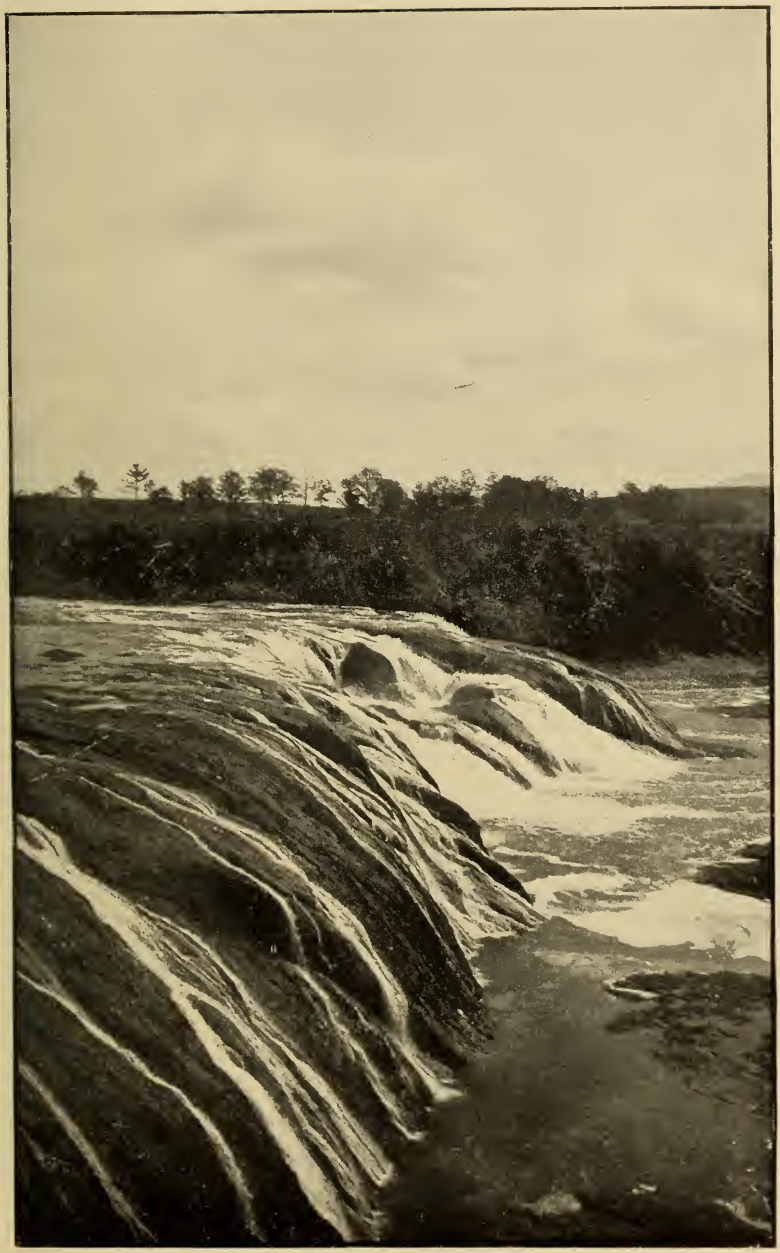
There are no records of any long-continued measurements of the discharge of Oswego River, whose drainage area at the mouth is 5,013 square miles. The minimum flow of this stream has been the subject of judicial inquiry. In August, 1875, in the case of Michael J. Cummings against owners and lessees of the water of the Varick Canal at Oswego, it was decreed:

(1) That the average flow of water from the Oswego River into the Varick Canal in low water in the summer months is about 45,000 to 50,000 cubic feet per minute; (2) that in extreme low water in the summer, and which usually occurs in the month of July or August, it is about 35,000 cubic feet per minute; (3) that the average flow of the whole three summer months is about 75,000 cubic feet per minute.

Varick Canal is entitled to receive one-half the total flow of the river, less the amount of water required for navigation purposes. Hence the average summer flow, according to the decree, is from 90,000 to 100,000 cubic feet per minute (1,500 to 1,670 cubic feet per second). The extreme low-water flow is placed at 70,000 cubic feet per minute for the whole flow of the river, or at 1,170 cubic feet per second, while the average flow of the whole three summer months is given at about 150,000 cubic feet per minute, or 2,500 cubic feet per second. From the foregoing figures we deduce an extreme minimum of perhaps 0.23 of a cubic foot per square mile per second, with an average of low water in the summer months of about 0.30 to 0.33 of a cubic foot per square mile per second.

LOW-WATER FLOW OF BLACK RIVER.

The drainage area of this stream at Watertown is 1,820 square miles. There is very little definite information as to either the maximum or the minimum flow. Aside from a few measurements made by engineers in the employ of the State at the time of construction of Black River Canal and a few made by Frank A. Hines in 1875, there do not appear to be any measurements of flow. As stated in the Report on Water Power of the United States, Tenth Census, probably the minimum flow



HIGH FALLS OF MOHAWK RIVER AT TIME OF LOW WATER.

in an ordinarily dry season may be taken at from 1,000 to 1,100 cubic feet per second for 24 hours. By reasoning from the data of Hudson River, it may be assumed that in very dry years the minimum flow will be less than this. Taking into account the large surface storage on the numerous lakes at the head waters, it is doubtful if Black River in its natural state will, while present forestry conditions are maintained, ever go below about 0.4 of a cubic foot per square mile per second, although it is claimed to have been less than this in 1849. As is shown in detail in another place, there are a large number of reservoirs upon the upper waters of this stream, which, if properly operated, may be expected to keep the low-water flow at a considerably higher figure than 0.4 of a cubic foot per square mile per second, that figure relating to the natural flow of the stream only.

LOW-WATER FLOW OF MOHAWK RIVER.

The drainage area of this stream is 3,400 square miles. According to David H. Van Auken, the engineer of The Cohoes Company, at Cohoes, the minimum flow of Mohawk River does not exceed 800 cubic feet per second, or 0.235 cubic foot per square mile per second. Since considerable water is taken from Mohawk River for the supply of Erie Canal, probably Mr. Van Auken's statement relates to the amount realized for water power at Cohoes, and, in the absence of definite figures as to the amount abstracted for the canal, must be taken as somewhat general. There is, however, a well-defined feeling that the minimum flow of the Mohawk has been gradually decreasing during the last twenty or twenty-five years, due probably to decreasing deforestation of the drainage area.

LOW-WATER FLOW OF HUDSON RIVER.

The drainage area above Mechanicville is 4,500 square miles. Measurements have been made at Mechanicville since October, 1887, the record of which to November, 1896, is presented in the tables on page 82. The natural flow of this stream is somewhat obscured by the presence of a considerable number of lumbermen's reservoirs on its head waters, the total storage of which aggregates about 4,000,000,000 cubic feet. The month of minimum run-off for the whole period covered by the measurements was July, 1888, the mean for the month being 1,537 cubic feet per second, or 0.39 inch on the watershed. For short periods the mean flow has been less than this. Thus, from August 14 to 19, 1890, the mean flow was 1,080 cubic feet per second; also, from October 2 to 6, 1891, inclusive, the mean flow is given at 1,080 cubic feet per second. For 4,500 square miles drainage area this gives 0.24 cubic foot per second. Taking the diversion for the supply of Champlain Canal into account, we have about 0.29 cubic foot per square mile per second as the actually observed minimum flow.

The figures show, moreover, that the minimum of 0.29 of a cubic foot per second has occurred for only two periods, one of six days and the other of five days, a total of eleven days for the whole period covered by the measurements. For July, 1888, the mean flow, including the diversion which was then occurring for the supply of Champlain Canal, may be taken at 0.37 of a cubic foot per square mile per second. For October, 1891, the mean flow for the whole month was 1,472 cubic feet per second, or, including the diversion to the Champlain Canal, 0.36 of a cubic foot per square mile per second. In July, 1890, the mean flow for the month was 1,950 cubic feet per second, and in several other months, as July, 1893, July, 1895, and September and October, 1895, the mean monthly flow varied from about 2,600 to 2,700 cubic feet per second. Hence we may say that for any business where it is not absolutely indispensable to have permanent power, water power on Hudson River may be developed up to the limit of about 0.4 of a cubic foot per square mile per second, with a prospect of not being interrupted on account of low water more than a few days in each year. For electric power, however, or any application of water power requiring a permanent power every day in the year, the development ought not to be based, under present conditions, on more than about 0.24 to 0.25 of a cubic foot per square mile per second, these latter figures relating especially to that portion of the river from which water is diverted for the supply of Champlain Canal. At points above the Glens Falls feeder the indications of the available data are that permanent power developments may be made up to 0.3 of a cubic foot per square mile per second. As is shown in the section on the water power of Hudson River, nearly all of the plants on that stream are developed far beyond these figures.

LOW-WATER FLOW OF CROTON RIVER.

The drainage area above the point of measurement is 338 square miles. The minimum flow of the main Croton River above the point of measurement, as given by J. J. R. Croes, is 0.178 of a cubic foot per square mile per second. The minimum flow of West Branch of Croton River, with a drainage area of 20.4 square miles, is given at 0.02 cubic foot per square mile per second. The lowest mean monthly flow in the period from 1870 to 1896, covered by the table on pages 83 to 85, is for the month of September, 1870, in which month the average daily run-off was 69,401,200 gallons or 9,265,800 cubic feet in 24 hours. These figures give 7.5 cubic feet per second and 0.318 of a cubic foot per square mile per second.

SUMMARY OF KNOWLEDGE OF LOW-WATER FLOW.

Summarizing the present knowledge of the minimum flow of streams in New York, we may say that in western New York for streams like Genesee River, issuing from regions of heavy, compact soil, mostly

deforested, the minimum flows are likely to run as low as 0.1 of a cubic foot per square mile per second, and even less. Spring-fed streams in that region, and those with considerable lake-surface pondage, may be expected to be somewhat greater than this. For the central part of the State the information is too limited to permit of making other than general statements. It is probable, however, that Oswego River, the main stream of the central region, has by reason of its lake pondage and swamp area a minimum flow not much less than 0.3 of a cubic foot per square mile per second. The Mohawk and the upper Hudson may also be placed, while their present condition of forestation is maintained, at a minimum of about 0.3 of a cubic foot per square mile per second. This figure also appears to apply to the Croton drainage area, where there are considerable sand areas, which compensate for the limited forestation. The streams of Long Island issuing from sand plains will give larger yields, the measurements showing a run-off of 0.58 cubic foot per second per square mile drained. The streams of the northern part of the State, which issue from denser forests than the others, may be expected to give minimum yields somewhat in excess of 0.3 of a cubic foot per square mile per second. Little is known as to the yield of streams tributary to the Allegheny, Susquehanna, and Delaware rivers aside from the measurements of Eaton and Madison brooks by Mr. Jervis, in 1835. Apparently no measurements of any other of these streams have been made. It is probable, however, that many of them are not specially different in water-yielding capacity from the Neshaminy, Tohickon, and Perkiomen creeks in Pennsylvania.[1]

In view of the vast importance of a detailed knowledge of stream flow in the State of New York, on account not only of the canal interests of the last seventy-five years, but also on account of the great possibilities of water-power developments, it is a matter of surprise that more extended measurements of the inland streams have not been made.

[1] For details of the measurements of the Neshaminy, Tohickon, and Perkiomen creeks, see a paper, Observations on rainfall and stream flow in eastern Pennsylvania, by John E. Codman. Proc. Eng. Club of Philadelphia, Vol. XIV (July to September, 1897).

[For index, see Part II of this report—Water-Supply Paper No. 25.]

1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Bighorn Range and Bighorn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett; and "Preliminary report on the artesian areas of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton; and "Reservoirs for irrigation," by J. D. Schuyler.

1898.

Nineteenth Annual Report of the United States Geological Survey, 1897–98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1897," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton; and "Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

WATER-SUPPLY AND IRRIGATION PAPERS, 1896–1899.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton, 1898.
13. Irrigation systems in Texas, by William Ferguson Hutson, 1898.
14. New tests of pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems in the Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.

In addition to the above, there are in various stages of preparation other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. [Approved June 11, 1896; Stat. L., vol. 29, p. 453.]

The maximum number of copies available for the use of the Geological Survey is 1,000. This number falls far short of the demand, so that it is impossible to meets all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general requests, such as to have all of the series sent indiscriminately.

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THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 25

WATER RESOURCES OF THE STATE OF NEW YORK
PART II.—RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation, prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888–89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889–90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890–91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; and "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891–92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; and "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892–93, Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W J McGee; "Natural mineral waters of the United States," by A. C. Peale; and "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

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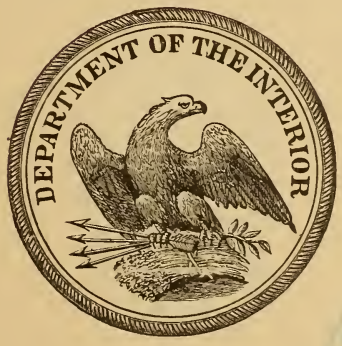
No. 25



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WATER RESOURCES

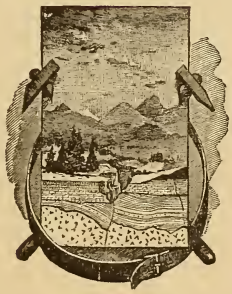
OF THE

STATE OF NEW YORK

PART II

BY

GEORGE W. RAFTER



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CONTENTS.

	Page.
Letter of transmittal	107
Water-storage projects	109
Genesee River storage reservoir	109
Preliminary investigations	110
Interests to be served	111
Investigation of the flood of 1865	112
Mount Morris sites	113
Portage site	114
Comparison of Mount Morris and Portage sites	122
Summary	124
Water storage on Hudson River	125
Early surveys	125
Recent investigations	127
Reservoir sites on Sacundaga, main Hudson, and Schroon rivers	128
Effect of proposed storage on river flow	132
Summary	134
Development of water powers	135
Power development at Niagara Falls	135
Niagara Falls Hydraulic Power and Manufacturing Company	136
Niagara Falls Power Company	138
Power plant at Massena, on St. Lawrence River	143
Inland waterways	144
Trade and commerce of Hudson River	144
State canals	145
Early history	145
Growth and decline of canal transportation	151
Cost and revenues of the New York State canal system	154
Improvement of Erie Canal	155
Description of the canals now in operation, and their water supply	157
Eastern division of Erie Canal	158
Water supply of the eastern division	158
Middle division	161
Reservoirs of the middle division	164
Western division	165
Ship-canal projects and water supply	166
Loss of water from artificial channels	173
Use and value of water power	178
Water power of Erie Canal	178
Power at Black Rock	178
Power at Lockport	179
Power at Medina	182
Selling price of water power	184
State ownership of inland waters	186
Future use of water power in New York	188
Obstructive effect of frazil or anchor ice	190
Water yield of sand areas of Long Island	191
Index	199

ILLUSTRATIONS.

Page.

PLATE I. Upper fall of Genesee River at Rochester, New York, at time of flood 112

II. East side of Genesee Gorge at site of proposed Portage dam 114

III. *A*, Lumberman's dam on Cedar River; *B*, Lumberman's dam on Indian River 126

IV. *A*, The George West Paper Mill on Hudson River at Hadley, New York; *B*, Hudson River Pulp and Paper Company's mills at Palmer Falls on Hudson River, New York 132

V. *A*, Glens Falls Paper Mill at Fort Edward, New York; *B*, Dam of the Hudson River Power Transmission Company during construction 134

VI. Power house of the Niagara Falls Hydraulic Power and Manufacturing Company 136

VII. Penstock of the Niagara Falls Hydraulic Power and Manufacturing Company 138

VIII. *A*, Power house of Niagara Falls Power Company; *B*, Outlet of tunnel of Niagara Falls Power Company 140

IX. *A*, Erie Canal at Buffalo, New York; *B*, Black Rock guard lock on Erie Canal 148

X. Effect of decrease of business on Erie Canal 152

XI. Erie Canal at Little Falls, New York 158

XII. Erie Canal at Syracuse, New York 162

FIG. 1. Map of drainage area of Hudson River above Glens Falls 126

2. General plan of development of the Niagara Falls Hydraulic Power and Manufacturing Company 137

3. Map of Niagara Falls and vicinity showing location of the great tunnel 139

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, November 26, 1898.

SIR: I have the honor to transmit herewith a manuscript on the Water Resources of the State of New York, prepared by Mr. George W. Rafter, and to recommend that it be published as one of the series of papers on Water Supply and Irrigation.

This manuscript is a continuation of the material printed in Water-Supply Paper No. 24, which related mainly to the physical conditions of river systems of the State of New York, and particularly to the available water supply, the floods, and the low water of some of the typical streams. In the present paper a discussion is given of water-storage projects and of the development of water power and waterways. The paper as originally presented was intended for publication as a whole in one of the annual reports. This was found impracticable, and to secure publication at an early date it has been necessary to subdivide the manuscript to conform with the limitations imposed regarding the size of papers in this series. In spite of this disadvantage it is believed that the information contained in these two papers (Nos. 24 and 25) will be of value not only to the people of New York, but to those of other States.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF NEW YORK, PART II.

By GEORGE W. RAFTER.

WATER-STORAGE PROJECTS.

Among the projects for storing water for power and other purposes are two of special importance with which the author has been concerned; the first of these is on Genesee River and the second on Hudson River. The following statements are for the most part condensed from more detailed reports in the Annual Report of the State Engineer and Surveyor for 1896.

GENESEE RIVER STORAGE RESERVOIR.

A general description of this river has been given in Part I (Water-Supply Paper No. 24), on page 25; its discharge measurements have been discussed on page 70, and reference has been made on page 90 to the low-water flow, indicating that during the summer the available supply is small. In spite of this fact, development of water power has proceeded rapidly. As shown by the reports on the Water Power of the United States in the Tenth Census (1880), the total water power on Genesee River from Rochester to Portage in 1882 was 6,882 net horsepower. An examination of the amount in use on the same reach of river in 1896 showed that the total, based on manufacturers' rating of wheels, was 19,178 net horsepower, or based on the manufacturers' statements of the quantity of water required to operate the wheels, and allowing 75 per cent efficiency of the water, the total power developed by the wheels in place in 1896 is found to be 17,248 net horsepower, or about three times that in 1882. In comparison with the figures it should be noted that for several months during the summer and fall of 1895 the total power did not exceed 6,000 horsepower. The same condition has existed during the dry period of a number of years previous, but not so seriously as in the fall of 1895.

PRELIMINARY INVESTIGATIONS.

The increased demand for power, as well as the serious summer droughts, led to the formulation of a project for constructing a storage reservoir at some point on the head waters of Genesee River for assisting the summer flow. The first project included the development of the basin of Honeoye Lake to its full capacity, surveys having been made for that purpose in 1887 and 1888. It appeared, however, that the yield of this drainage basin, which is only about 43.5 square miles, was hardly adequate for the results desired, the estimate showing that even when developed to its full capacity it could not be depended on to furnish, in a dry year, more than 75 cubic feet per second, while the exigencies of the case demanded at least several hundred cubic feet per second. The project of building a large storage reservoir on upper Genesee River was then formulated by the Rochester Chamber of Commerce.

In the meantime a number of breaks on the long level of the Erie Canal, which extends from the foot of the locks at Lockport to the eastern part of the city of Rochester, a distance of about 62.5 miles, had emphasized the importance of the State's providing additional water for feeding the canal east of Rochester. For this purpose the construction of a large storage reservoir was advocated by the Rochester Chamber of Commerce as a State work, with the result that under a resolution of the senate dated March 21, 1889, the State engineer and surveyor was directed to make a general investigation in regard to the possibility of storing water on the upper Genesee. The report made under the authority of this resolution appears in the Annual Report of the State Engineer and Surveyor for the year 1890. In 1892, under authority of a concurrent resolution dated March 15 of that year, Governor Flower appointed a commission consisting of Evan Thomas, Judge Charles McLouth, and John Bogart to investigate and report on the whole question of storage on the upper Genesee. This commission examined the site of the proposed reservoir and reported that it was entirely feasible to construct a large reservoir on the upper Genesee River, the site especially considered by the commission being in the Genesee canyon or gorge, a short distance above Mount Morris, already described in Part I.

As the result of the recommendations of this commission, the sum of $10,000 was appropriated at the legislative session of 1893 for the purpose of studying in detail the several proposed sites for dams in the canyon of Genesee River, above Mount Morris. At that time the work was placed in charge of the author, and has since remained in his hands.[1]

At the legislative session of 1894 a bill to construct a dam in the canyon a short distance above Mount Morris passed the senate, but

[1] The result of the studies in 1893 may be found in the Annual Reports of the State Engineer and Surveyor for the fiscal years ending September 30, 1893 and 1894.

failed in the assembly. At the session of 1895 a similar bill passed both the senate and assembly, but was vetoed by Governor Morton, largely on the ground that the bill as passed made no provision for the owners of the water power and other interested parties bearing any portion of the expense. In his veto Governor Morton expressed the belief that if the State should determine to build a dam on Genesee River some provision should be made by which the city of Rochester—and possibly other localities interested in the work—might contribute to the expense of construction. Governor Morton also pointed out that if the proposed canal enlargement be approved by the people public sentiment might justify the construction of a storage dam on Genesee River for canal purposes. On the other hand, if the proposition to deepen the canal should not be approved the question would still remain whether such a dam might not be desirable for the purpose of regulating the river and increasing the water power thereon.

In order to complete the preliminary investigations relative to the proposed Genesee storage, Governor Morton, in 1896, approved an additional appropriation, which was expended during the summer of that year in completing the additional surveys. To the present time the State has expended on preliminary investigation of the Genesee storage project the following amounts: In 1890, $3,000; in 1892, $7,000; in 1893, $10,000; in 1896, $10,000; in all, $30,000. As a result of this expenditure complete plans and specifications have been prepared as shown in the Annual Report of the State Engineer and Surveyor for 1896.[1]

INTERESTS TO BE SERVED.

The following are the interests to be served by the construction of these extensive storage works on Genesee River:

(1) The flow of the river would be regulated, thus effectually preventing in the future the devastating floods which occurred in 1815, 1835, 1857, 1865, 1889, 1893, 1894, and 1896. The floods in the years just

[1] By way of presenting a full list of the work on the Genesee storage, reference may be made to the special report of John Bogart, State engineer and surveyor, in Appendix F of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1890. The reports of Messrs. Bailey and Kibbe, assistant engineers to Mr. Bogart, are covered by the same reference. The report of Martin Schenck, State engineer and surveyor, may be found at page 44 of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of E. Sweet, ex-State engineer and surveyor, as consulting engineer, may be found in Appendix H of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of the commissioners appointed in 1892 by Governor Flower may be found in Senate Doc. No. 23, 1893. The first report of the writer may be found in Appendix G of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The second report may be found in Appendix E of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1894. The work done in 1896 is described at length in the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1896. See also a paper by the writer, The Genesee River storage and its relations to the Erie Canal and the manufacturing interests of western New York, prepared for the Rochester Chamber of Commerce. This paper contains a large amount of historical information not given in the official reports. Governor Morton's veto may be found in the Governor's State Papers for 1895.

enumerated were especially severe, but floods not so severe, yet doing considerable damage, have occurred in several of the intervening years. The most severe flood was that of 1865, which destroyed fully $1,000,000 worth of property in the city of Rochester.

(2) Water would be supplied for the enlarged Erie Canal. According to Mr. Bogart's report of 1890, there should have been provided a storage on Genesee River of 1,500,000,000 cubic feet for the purpose of supplying Erie Canal as it existed at that date. Estimates made in 1896 show that for the purpose of fully supplying the enlarged canal, as now in process, there should be made a storage on Genesee River of 2,500,000,000 cubic feet.

(3) The agricultural production of the broad level area included in Genesee Valley between Rochester, Mount Morris, and Dansville, estimated at from 60 to 80 square miles, might be greatly increased by moderate irrigation if the flood contingency was removed and the proper irrigation channels were constructed.

(4) Considerable sanitary benefit to this section would result from the increased flow during the low-water period through the proposed regulation. The entire sewage at Rochester, a city of 160,000 inhabitants, now passes into Genesee River. The channel of this stream, between the foot of Lower Falls at Rochester and Lake Ontario, is so broad and deep that during the time of extreme low water in the summer and fall the current is scarcely perceptible. The sewage of the city therefore lodges in this section, producing a serious nuisance. The regulation of the river, by preventing floods, would also improve the sanitary condition of the broad upper valley, where the annual overflow has been shown to cause more or less sickness.

(5) The water power would be increased. Wheels are now set on Genesee River capable of producing, at the manufacturers' rating, 19,178 horsepower, while the low-water flow of the stream does not exceed about 6,000 horsepower. The regulation as finally proposed would produce much more power than this.

In summation of the preceding points it may be urged, in general, that in constructing the proposed Genesee storage dam, in addition to the private interests to be conserved, public service of an extended character would be performed.

INVESTIGATION OF THE FLOOD OF 1865.

The great flood of March, 1865, worked such destruction that the legislature, on May 1 of that year, passed an act appointing commissioners to ascertain the cause of the inundation of the city of Rochester, what obstructions, if any, had been placed in the river, and what measures, proceedings, and remedies were necessary to guard against the recurrence of such an inundation. The commissioners appointed under this act examined carefully the evidence as to the flood, and arrived at the conclusion that there were three principal causes:

UPPER FALL OF GENESEE RIVER AT ROCHESTER, NEW YORK, AT TIME OF FLOOD

(1) The sudden melting of an immense body of snow which had accumulated during the previous winter.

(2) Obstructions caused by the bridge and embankment of what is now the New York, Lake Erie and Western Railway at Avon. The openings at this place are stated to have been adequate for ordinary floods, but entirely too small for the quantity flowing in March, 1865. Hence, at the time of greatest flow, the water stood three feet higher on the upper side of the embankment than on the lower side. The embankment finally gave way, thus allowing a large quantity of ponded water to flow suddenly down the river, filling the channel at Rochester beyond its carrying capacity.

(3) Obstruction of the channel of the river through the city of Rochester in such manner as to cause overflows into the Erie and Genesee Valley canals at that place. The commissioners also point out that the construction of the Erie Canal aqueduct is such as materially to increase the obstruction at Rochester.

From the best available figures the maximum flow at Rochester in the great flood of March, 1865, probably did not exceed about 40,000 cubic feet per second. The danger limit is reached when the flow at that place approximates 33,000 cubic feet per second.

The following are the openings of the several bridges, etc., spanning Erie Canal in the city of Rochester, as they exist at present: Court street bridge, 5,081 square feet; Main street, 3,367 square feet; Andrews street, 4,511 square feet; Central avenue, 4,450 square feet; Erie Canal aqueduct, 4,308 square feet.

As a chief cause of the 1865 flood the commissioners considered that cutting off the forests and clearing lands were likely to lead to heavier floods from year to year. In view, therefore, of what seemed to the commissioners a constant source of danger, they arrived at the conclusion that a much larger waterway through the city of Rochester was imperative. It may be here remarked that the waterway at Rochester is still substantially the same as in 1865; if anything, it has been somewhat contracted by various constructions since that date.[1]

MOUNT MORRIS SITES.

Referring to Mr. Bogart's report of 1890, it is learned that the investigations of that year were general in their character. The work was carried on more particularly with reference to a location in Genesee River gorge, between Mount Morris and the foot of the Portage Falls. No detailed surveys were made further than necessary to make a general estimate of the cost of a dam 58 feet in height, which would store 1,500,000,000 cubic feet, the amount considered necessary for canal purposes alone. Such a dam, Mr. Bogart estimates, could be erected for about $1,000,000.

[1] For report of the commissioners appointed to investigate the causes of the inundation of the city of Rochester in March, 1865, see Ass. Doc. No. 117 (1866).

The work performed under the direction of the author, in 1893, was of an entirely different character. The report of 1890 having indicated the Mount Morris Canyon as a desirable location, with a number of sites pointed out, of which general investigations had been made, it became desirable to investigate those sites in detail and to prepare close estimates of the cost of constructing dams at each. Detailed investigations were accordingly made of the three sites favorably reported upon in 1890, the results of which may be found in the Annual Reports of the State Engineer and Surveyor for 1893 and 1894, where estimates of the cost of the several dams are also given in detail. Referring to the estimates, it appears that at site No. 1, in Mount Morris Canyon, a dam raising the water surface 130 feet would cost, if built of concrete alone, $2,450,000, but if built with sandstone faces throughout, except for the spillway, where granite is provided, the estimated cost would become $2,590,000. A dam of the same height at site No. 2, if built throughout of concrete, would cost $2,600,000, but with sandstone faces and independent spillway the cost would be $2,720,500, or, with roadway, $2,785,000.

In regard to the total storage to be obtained in Mount Morris Canyon the following are the figures at sites Nos. 1 and 2, the two sites chiefly considered: At site No. 1 a dam 130 feet in height will store 7,700,000,000 cubic feet, and at site No. 2 a dam of the same height will store 7,040,000,000 cubic feet. Since no conclusion has been reached as to which of these sites to adopt, for the purposes of comparison a mean of 7,370,000,000 cubic feet has been taken as the approximate available storage, and the mean of $2,785,000 as the approximate total cost. On this basis the estimated cost of this storage becomes $377.88 per million cubic feet stored.

PORTAGE SITE.

As already stated, the investigations of the Genesee River storage project were finally completed in 1896. In that year detailed surveys were made of a new site known as Portage site (shown on Pl. II), the proposed dam to be located at Portage, about 1,400 feet above the Erie Railway bridge, at a point where the gorge presents extremely favorable conditions for the erection of a high dam. At this place solid rock exists immediately in the bed of the river, with only a couple of feet of water flowing over it, and also extends high up on the bluffs at either side, whereas at all of the sites in the gorge near Mount Morris the rock was only found at from 15 to 20 feet below the water surface and of such an open texture as to require cut-off trenches about 30 feet deep, or to a total depth of nearly 50 feet below the water. The proposed Portage dam is also 500 feet vertically above the previously mentioned dam site, thus rendering that additional number of feet available for power purposes—a fact which

EAST SIDE OF GENESEE GORGE AT SITE OF PROPOSED PORTAGE DAM

places a materially different aspect on the commercial side of the Genesee River storage project.

A short distance above the proposed Portage site the upper Genesee Valley broadens out to a width in places of from one to two miles, although the general width of the valley does not exceed, for several miles in extent longitudinally, about one mile. It narrows in two or three places to a less width than this. The valley is now a good agricultural region, in a fair state of cultivation, and presents, on the whole, as favorable conditions for farming as any similar valley in the State. The Western New York and Pennsylvania Railway passes through the middle of the valley on the line of the abandoned Genesee Valley Canal. Along the line of this railway the villages of Portageville, Rossburg, Wiscoy, and Fillmore are situated. The reservoir project includes the relaying of the railway above the flow line on the west side of the valley, as well as the removal of the villages named. The total area below the flow line is 12.4 square miles and the entire area proposed to be taken for reservoir purposes, including a strip 10 feet vertically above the flow line, is 13.7 square miles. The project also includes the removal of several cemeteries, the building of highway bridges across the reservoir, and the construction of a roadway entirely around the same.

Without having made a detailed canvass, it is estimated that the present population of the proposed Portage reservoir site, in the villages and on the farms, is about 1,200. In reference to dispossessing this number of people of their homes for the purpose of creating a large storage reservoir, it may be said that such a proceeding is not only not uncommon in this State, but that the population to be removed in the case of the new Croton reservoir is far greater than at the Portage reservoir. According to maps furnished by the Croton water department, it appears that the new Croton reservoir includes the taking of either the whole or parts of something like three large villages and nine or ten hamlets. The total population to be removed from the submerged area of the new Croton reservoir is not given, but actual inspection of maps of the proposed sites indicates that it must be several times larger than the number to be dispossessed at Portage. The villages of Katonah, Purdy Station, and Croton Falls are much larger than any of the villages in the Portage reservoir site. The main line of the New York and Northern Railroad passes for several miles through the valley and requires relocating above the flow line, the same as is proposed for the Western New York and Pennsylvania Railway along the Portage reservoir. It appears, therefore, that the city of New York is now doing under State laws everything in the way of so-called radical change which it is proposed to do at Portage. In both cases the sufficient reason for these changes may be found in the better meeting of public necessities.

The estimated cost of the proposed Portage reservoir, including land damages, dam, reconstruction of railway, removal of cemeteries, the cutting of all timber within the drainage areas, the construction of highway bridges, etc., is $2,600,000, the storage to be provided by this expenditure amounting to 15,000,000,000 cubic feet; at this rate the cost per million cubic feet stored is $173.33. The main characteristics of the proposed reservoir are shown by the following table, condensed from pages 708 and 709 of the report of the State Engineer and Surveyor of New York for 1896:

Capacity of proposed Portage reservoir.

Elevation of water surface above sea level.	Area of water surface.	Total volume of water in reservoir.	Inches on watershed.
Feet.	*Sq. miles.*	*Cubic feet.*	
1,100.0	0.2320	101,400,000	0.044
1,105.0	0.5330	217,623,000	0.094
1,110.0	0.8340	333,900,000	0.143
1,115.0	1.1350	450,100,000	0.194
1,120.0	1.4357	566,300,000	0.244
1,125.0	2.0659	942,100,000	0.406
1,130.0	2.6692	1,318,000,000	0.567
1,135.0	3.3264	1,694,000,000	0.729
1,140.0	3.9566	2,070,000,000	0.891
1,145.0	4.5255	2,780,000,000	1.196
1,150.0	5.0944	3,490,000,000	1.502
1,155.0	5.6633	4,200,000,000	1.808
1,160.0	6.2322	4,910,000,000	2.113
1,165.0	6.8293	5,945,000,000	2.559
1,170.0	7.4264	6,980,000,000	3.004
1,172.0	7.6652	7,395,000,000	3.182
1,173.0	7.7846	7,602,000,000	3.271
1,175.0	8.0235	8,016,000,000	3.451
1,180.0	8.6206	9,051,000,000	3.896
1,185.0	9.4362	10,366,000,000	4.462
1,190.0	10.2518	11,681,500,000	5.016
1,195.0	11.3007	13,257,000,000	5,710
1,200.0	12,3495	15,000,000,000	6.458

Comparing the foregoing statements of cost with those made on the preceding page with reference to the cost of the proposed reservoir in Mount Morris Canyon, it appears that at Portage a storage of 15,000,000,000 cubic feet can be made for somewhat less than the cost

of 7,300,000,000 cubic feet at Mount Morris; or, as a general statement, we may say that a given expenditure at Portage produces double the storage that it will produce at Mount Morris. The Portage reservoir develops the full capacity of the drainage area for such a dry year as 1895. It is considered that this full development is necessary in order to obtain the most satisfactory results in river regulation.

As reasons in detail for preferring Portage site to that at Mount Morris, the following may be mentioned:

(1) The Portage site affords more water for a given expenditure.

(2) The Portage site is considered safer than the Mount Morris site. As shown in the Genesee Storage Reports of 1893–94, the shales at Mount Morris are open; and while it is, without doubt, possible to make a safe dam there, it would be at much greater cost than at Portage. In view of the large storage provided at either place, the dam must be absolutely safe, as its failure would work vast destruction.

(3) The material for the dam is nearly all on the ground at Portage, while at Mount Morris it needs to be brought from a distance.

(4) The Portage site affords greater water-power development. With the Genesee storage dam located at Mount Morris the total head on which the storage can be applied is 282 feet, while with a dam at Portage the total head on which the stored water may be applied is 782 feet.

(5) On account of great depth of foundation at Mount Morris, it would be necessary to expend over $1,000,000 before the dam could be brought to the level of the present water surface. The conditions are such that the floods of every spring would sweep over the work, obliterating all evidence that any money had been expended, which must necessarily continue for at least two or three years, until the foundations could be fully placed. At Portage, on the other hand, a good foundation is found near the water level. Indeed, the difference in cost of foundation is such that nearly the total expenditure at Mount Morris is for the dam, the flowage ground costing only $75,000, while at Portage the estimated cost of the dam is only $1,000,000, the balance of the expenditure there being for right of way, change of railway line, etc.

The proposed regulation of Genesee River has been computed on the basis of a minimum discharge of 300 cubic feet per second, in the case of a reservoir storing 7,500,000,000 cubic feet, and also on a basis of 457 cubic feet per second in the case of a reservoir storing 15,000,000,000 cubic feet. As to the reason for fixing upon these minimums, it may be remarked that in river regulation the outflow from the storage reservoir should be so arranged as to make the benefit to all parts of the stream equal. Especially is this proposition true when, as in the present case, there is water power distributed

throughout the whole extent of the stream below the storage point. Obviously the way to do this is to plan for an outflow proportional to the drainage area. In the present case we have a drainage area at Rochester of 2,365 square miles, and one of 1,000 square miles above Portage, or the area above Rochester is about 2⅓ times the area above Portage. The minimum regulated flow at Rochester may justly be made 2.365 times the assumed minimum flow at Portage.

Assuming 680 cubic feet per second as the flow below which the stream will never be allowed to fall at Rochester, we have for a reservoir storing 7,500,000,000 cubic feet a corresponding minimum outflow from the reservoir of 300 cubic feet per second, or for a storage of 15,000,000,000 cubic feet an outflow of 457 cubic feet per second, the latter figure being arrived at by assuming the maintenance of a minimum flow at Rochester of at least 1,080 cubic feet per second. The computations of the tables on pages 119 to 121 are carried out on this basis. The regulated flows for the month of May are greater than for the other months. They are also greatest during the months of canal navigation, the addition being made in order to provide for the quantity of water to be taken for the enlarged Erie Canal, which quantity has been fixed at 80 cubic feet per second for every month of the navigation season except May, and at 177 cubic feet per second for that month, the excess quantity for the month of May being required in order to provide for filling the canal at the beginning of the month.

The first table shows the effect on the flow of Genesee River from June, 1894, to November, 1896, inclusive, as influenced by the storage at Portage of 7,500,000,000 cubic feet of water, provided at least 300 cubic feet per second is allowed to flow continually at Portage, and at least 600 cubic feet per second is always flowing at Rochester in addition to the amount required for canal purposes. The figures given in the left-hand column show the proposed minimum flow at Rochester, this being the 600 second-feet above noted, together with 80 second-feet for the canal for the months from June to November, inclusive, and 177 second-feet for the month of May. The next two columns give the discharges at Rochester and Portage under natural conditions. The fourth column is the difference between these, or the quantity of water entering the river below Portage, and next to this is the minimum amount to be added at Portage in order to maintain the proposed minimum flow at Rochester of 600 cubic feet per second, not including the amount taken by the canal. The quantity available at Rochester for power purposes is shown in the next column, and is obtained by adding the flow at Rochester, less the flow at Portage, to the actual flow from Portage reservoir and the surplus flowing over the spillway at Portage reservoir, and then deducting the quantity taken by the canal.

Regulation of Genesee River by storage at Portage.

[With storage of 7,500,000,000 cubic feet at Portage and flow of at least 600 second-feet at Rochester.]

Month.	Proposed minimum flow at Rochester.	Natural flow at Rochester.	Natural flow at Portage.	Flow at Rochester less flow at Portage.	Minimum amount to be added at Portage.	Available at Rochester.	Actual flow from Portage reservoir.	Surplus flowing over spillway.
1894.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
June	680	2,321	981	1,340	.....	2,205	300	645
July	680	292	123	169	511	600	511	.....
August	680	442	187	255	425	600	425	.....
September	680	1,963	830	1,133	.....	1,353	300	.....
October	680	899	380	519	161	739	300	.....
November	680	1,729	731	998	.....	1,505	300	287
December	600	1,256	531	725	.....	1,241	300	216
1895.								
January	600	1,335	565	770	.....	1,330	300	260
February	600	495	209	286	314	600	314	.....
March	600	3,985	1,684	2,301	.....	3,867	300	1,266
April	600	4,257	1,800	2,457	.....	4,197	300	1,440
May	777	385	163	222	555	600	555	.....
June	680	283	120	163	517	600	517	.....
July	680	232	98	134	546	600	546	.....
August	680	254	108	146	534	600	534	.....
September	680	221	93	128	552	600	552	.....
October	680	230	97	133	547	600	547	.....
November	680	993	420	573	107	793	300	.....
December	600	2,710	1,146	1,564	.....	1,864	300	.....
1896.								
January	600	964	408	556	44	856	300	.....
February	600	2,005	848	1,157	.....	1,457	300	.....
March	600	6,158	2,604	3,554	.....	4,999	300	1,145
April	600	7,172	3,033	4,139	.....	7,155	300	2,716
May	777	347	147	200	577	600	577	.....
June	680	654	277	377	303	600	303	.....
July	680	501	211	290	390	600	390	.....
August	680	416	176	240	440	600	440	.....
September	680	327	138	189	491	600	491	.....
October	680	3,667	1,556	2,111	.....	2,331	300	.....
November	680	1,728	731	997	.....	1,486	300	269

The actual flow from Portage reservoir is taken to be the minimum of 300 cubic feet per second ordinarily assumed, plus the amount necessary to make up the deficiency in the quantity of water entering the river at points between Portage and Rochester. The last column that on the right-hand side, shows the surplus flowing over the spillway at Portage reservoir during the comparatively few months when the natural flow has filled the reservoir, supplied all demands of evaporation from the surface, and still is in excess.

The next table exhibits the condition of the reservoir from month to month under the above conditions. The figures are given not in cubic contents but in equivalent depth in inches on the total tributary watershed of 1,000 square miles. The reservoir is assumed to be full at the beginning and end of June, 1894, the total storage of the reservoir being equivalent to 3.23 inches in depth on the watershed. The total waste from June 1, 1894, to December 1, 1896, equals, under the conditions of this table, 9.36 inches on the watershed.

Flow into and from Portage reservoir under the conditions assumed.

[In inches on watershed.]

Month.	Inflow to reservoir.	Outgo from reservoir.			Excess.	Deficiency.	In reservoir at end of month.	Wasted.
		Evaporation.	Amount to stream.	Total outgo.				
1894.								
June	1.10	0.03	0.33	0.36			3.72	0.72
July	.14	.04	.59	.63		0.49	2.76	
August	.22	.04	.49	.53		.31	2.45	
September	.93	.03	.33	.36	0.57		3.02	
October	.44	.02	.35	.37	.07		3.09	
November	.82	.01	.33	.34	.48		3.25	.32
December	.61	.01	.35	.36	.25		3.25	.25
1895.								
January	.66	.01	.35	.36	.30		3.25	.30
February	.22	.01	.33	.34		.12	3.13	
March	1.94	.01	.35	.36	1.58		3.25	1.46
April	2.01	.02	.33	.35	1.66		3.25	1.66
May	.19	.04	.64	.68		.49	2.76	
June	.13	.04	.58	.62		.49	2.27	
July	.11	.03	.63	.66		.55	1.72	
August	.12	.03	.61	.64		.52	1.20	
September	.10	.02	.62	.64		.54	.66	
October	.11	.01	.61	.62		.51	.15	
November	.47	.01	.33	.34	.13		.28	
December	1.32	.01	.35	.36	.96		1.24	

Flow into and from Portage reservoir under the conditions assumed—Cont'd.

[In inches on watershed.]

Month.	Inflow to reservoir.	Outgo from reservoir.			Excess.	Deficiency.	In reservoir at end of month.	Wasted.
		Evaporation.	Amount to stream.	Total outgo.				
1896.								
January	.47	.01	.35	.36	.11		1.35	
February	.91	.01	.32	.33	.58		1.93	
March	3.00	.01	.35	.36	2.64		3.25	1.32
April	3.38	.02	.33	.35	3.03		3.25	3.03
May	.17	.03	.67	.70		.53	2.72	
June	.39	.04	.34	.38	.01		2.73	
July	.24	.04	.45	.49		.25	2.48	
August	.20	.04	.51	.55		.35	2.13	
September	.16	.02	.57	.59		.43	1.70	
October	1.74	.02	.35	.37	1.37		3.07	
November	.82	.01	.33	.34	.48		3.25	.30

Similar tables might be given, showing the regulation of the river as affected by the storage at Portage of 15,000,000,000 cubic feet of water for the same period, with at least 457 cubic feet per second always flowing at Portage, and at least 1,000 cubic feet per second at Rochester, in addition to the amount required for the canal. The chief difference is that during only three months of this period would there be any overflow through the spillway, the total waste equaling 2.11 inches. This would be in June, 1894, 521 second-feet; in April, 1895, 1,058 second-feet; in April, 1896, 350 second-feet. The amount at Rochester under the same conditions would be in no case below 1,000 second-feet.

It may here be pointed out that had the enlarged canal been in operation in July, 1894, and taking the estimated quantity of 80 cubic feet of water per second from Genesee River, the amount of water going to the canal would have been 27.4 per cent of the total flow of the river for that month; in August 18.1 per cent; in May, 1895, 46 per cent; in June, 28.3 per cent; in July, 34.5 per cent; in August, 31.5 per cent; in September, 36.2 per cent; and in October, 34.8 per cent. In May, 1896, the canal would have taken 51.3 per cent of the total flow of the river for that month; in June, 12.2 per cent; in July, 15.9 per cent; in August, 19.2 per cent; and in September, 24.5 per cent. It appears, therefore, that the taking of 80 cubic feet per second from Genesee River for canal purposes is a very serious matter to the water power of the stream and is unjustifiable, unless it be clearly shown that the addition to the wealth of the State is greater

than if the water were used for supplying power. The actual damage resulting from taking at times 50 per cent of the unregulated flow of the stream is about as follows: As shown on a previous page, the minimum flow of the river is capable of producing 6,727 gross horsepower, or, what is the same thing, assuming 75 per cent efficiency, 5,046 net horsepower. One-half of the low-water power may therefore be taken at 2,523 net horsepower.

So long as the possibility exists of a draft upon the river equal to one-half of its minimum flow, this 2,523 net horsepower is practically rendered useless to its owners by reason of the uncertainty as to the exact time of the draft, or if not rendered useless, is far less valuable than if it were absolutely permanent power. In enforcing this view it may be pointed out that Rochester is a manufacturing town, made up chiefly of establishments using comparatively small quantities of power at each place, but that the power must still be continuous every day; that is to say, it must be absolutely permanent power. So long, therefore, as one-half the total minimum power of the stream is subject to stoppage during any month, the manufacturers will preferably use steam power, on account of its permanency, even at considerably greater expense. Bearing on this view, the fact may be pointed out that the use of soft coal in Rochester for steam purposes is stated as 500,000 tons a year, which, at an average price of $2.40 per ton, amounts to the sum of $1,200,000 annually. It may be considered settled, therefore, that water power is valuable at Rochester, and that anything which tends to reduce the permanent power 50 per cent is a very serious matter to the manufacturers of the city.

COMPARISON OF MOUNT MORRIS AND PORTAGE SITES.

As a final point in the discussion of Genesee River storage, comparison will be made between the Mount Morris project, storing 7,370,000,000 cubic feet, at a cost of $2,785,000, and the Portage project, storing 15,000,000,000 cubic feet, at an estimated cost of $2,600,000, for the purpose of determining the relative commercial advantages.

With the reservoir at Mount Morris storing 7,370,000,000 cubic feet there is 282 feet fall, on which 7,370,000,000 cubic feet, less the quantity required for the canal, may be applied for power purposes. As already explained, the constant outflow from the reservoir would never be less than 300 cubic feet a second. Continuous power development under this plan would, therefore, be based on 300 cubic feet a second at Mount Morris, something more than this at Geneseo and York, and on 600 cubic feet a second at Rochester. On this basis of computation it appears that the total permanent, continuous power to be realized from a reservoir storing 7,370,000,000 cubic feet and located in the Mount Morris Gorge would be 18,327 gross horsepower.

In regard to the increase in water power, the effective value of the storage will be the amount of permanent power above the low-water

power of the stream. As already stated, the total permanent power for the unregulated stream is 6,727 gross horsepower. The gain due to the storage is, therefore, 11,600 gross horsepower. Assuming a price of $10 per gross horsepower, we reach an annual return from the increased power of $116,000; but the Mount Morris reservoir is estimated to cost $2,785,000. If we assume the project carried out by a private company, with money at 5 per cent, the annual interest on the investment is $139,250—a sum $23,250 in excess of the probable annual income when all the power created shall have been brought into use; but there should be a sinking, maintenance, and repair fund of at least $25,000 a year, in order to repay the principal investment, which if taken into account increases the probable deficiency to $48,250 a year. It must be concluded, therefore, that with the present understanding as to the minimum run-off of Genesee River the project of a storage reservoir in Mount Morris Canyon, storing approximately 7,370,000,000 cubic feet of water, at a cost of $2,785,000, is commercially impracticable.

If we consider the Portage project in its financial aspects, where it is proposed to construct a reservoir storing 15,000,000,000 cubic feet of water, at a cost of $2,600,000, we reach the following results:

The total fall from just above the upper fall at Portage to the mean level of Lake Ontario is 785 feet, of which the greater portion is available for the development of water power. Without going into detail, we may place the permanent, continuous gross horsepower of the river, with a storage of 15,000,000,000 cubic feet at Portage, at the following figures:

Power of Genesee River after construction of reservoir at Portage.

	Gross horsepower.
Portage to Mount Morris	25,924
Mount Morris	835
Geneseo and York	624
Rochester	29,840
Total	57,223

Deducting from 57,223 gross horsepower the present permanent power of 6,727 gross horsepower, we have 50,496 gross horsepower as the net increase in the permanent water power of the stream due to the construction of the Portage reservoir. At $10 per gross horsepower, as before, the annual income when the power is utilized amounts to $504,960. The estimated cost of producing this vast increase in power is $2,600,000. Assuming an interest rate of 5 per cent, the annual interest is $130,000; adding to that amount $25,000 for sinking fund, maintenance, and repairs, the total annual expense becomes $155,000. The difference of $349,960 is the net annual income.

As already shown, when interest is taken into account, the Mount Morris project becomes commercially impracticable. The Portage project, on the other hand, shows an annual income, above interest account, sinking fund, maintenance, and repairs, of $349,950, which,

capitalized at 5 per cent, represents $6,999,000. If we assume 4 per cent, the capitalization of the annual income may be expected ultimately to represent $8,748,750.

SUMMARY.

Lack of space prevents discussion in greater detail of the Genesee River storage project, and the following summation is presented as embodying the main points of the discussion:

(1) Of the several available sites for reservoirs on Genesee River that at Portage is preferable to others, because it affords the largest storage at the smallest cost per unit volume.

(2) Serious floods have occurred a number of times in Genesee River at Rochester, the most serious being that of March, 1865. At least $1,000,000 loss resulted from that flood. The flood in April, 1896, was nearly as severe as the flood of March, 1865, although, as the river channel was clear, very little damage ensued.

(3) As the result of three years' measurements of Genesee River, it is determined that the minimum flow of the stream may for the entire year be as low as 6.67 inches on the watershed.

(4) A study of existing conditions shows that the Genesee River drainage area has been nearly denuded of forests, and hence that severe spring floods are likely to be frequent. For the same reason the summer flow of the stream is less than formerly.

(5) As a tentative conclusion, based on the data at hand, it may be said that deforestation of a drainage area may tend not only to increase floods somewhat, but to decrease materially the amount of the annual run-off.

(6) A comparison of the conditions existing on the drainage area of Genesee River with those of the upper Hudson, which is still largely in forest, shows less run-off under given conditions from the Genesee than from the Hudson, thus indicating the probable effect of the forest in increasing the run-off.

(7) As regards the upper Genesee drainage area, the forest has been removed by landowners who have commercially profited by such romoval; the effect, however, has been to injure permanently every riparian owner on the stream; hence it is proper that the State should spend money either in partially reforesting the area or in constructing river regulation works. The latter is preferable, because the benefits can be realized in a few years. If the State does not desire to construct such works, there should be no obstacles interposed to their construction by a private company.

(8) The proposed Portage reservoir will impound 15,000,000,000 cubic feet of water, at an estimated cost of $2,600,000, or at a cost of $173.33 per million cubic feet stored. It affords a permanent, continuous power above the present low-water flow of the stream of 50,496 gross horsepower, while the reservoir at Mount Morris affords only 11,600 horsepower above the present low-water power of the stream.

(9) Based on manufacturers' ratings, the present total developed water power of Genesee River from Portage to Rochester, inclusive, is 19,178 net horsepower; or, basing the amount of water power on the manufacturers' ratings of water required, and assuming 75 per cent efficiency on the wheels, the total power is 17,248 net horsepower, of which 16,683 net horsepower is within the limits of the city of Rochester.

(10) The enlarged Erie Canal will require 80 cubic feet of water per second from Genesee River for every month of the navigation season except May, and in that month a mean of 177 cubic feet per second.

(11) The present extreme low-water power of Genesee River at Rochester is 5,046 net horsepower, of which one-half, or 2,523 net horsepower, will be rendered very much less valuable to its owners because of the taking for the enlarged Erie Canal of 80 cubic feet per second in every month of the navigation season and 177 cubic feet per second in May.

WATER STORAGE ON HUDSON RIVER.

As noted in Part I of this paper, on page 33, Hudson River is divided at the Troy dam into the upper or water-power section and the lower or tidal portion. The proposed reservoirs are, as a matter of course, in the upper section, that above Troy.

EARLY SURVEYS.

The project for constructing storage reservoirs on the upper Hudson has been agitated for many years, the first surveys for this purpose having been made in 1874. In that year Prof. F. N. Benedict conducted surveys, and in his report proposed an extensive system of reservoirs. The chief interest attaching to this report is the proposition on the part of Mr. Benedict to build storage reservoirs at Blue Mountain, Racket, Forked, Beach, and Long lakes, and divert the water stored on these several lakes from their natural drainage into Racket River, to the south, thus making them artificially tributary to Hudson River. In proposing this diversion, Mr. Benedict apparently assumed that the State, in its sovereign capacity, could divert waters from one drainage basin to another without regard to the rights or wishes of the riparian owners.

In addition to the lakes already enumerated, which are naturally tributary to Racket River, Mr. Benedict proposed to make reservoirs of the following lakes and ponds in the upper Hudson drainage area: Round Pond, Catlin Lake, Rich Lake, Harris Lake, Lake Henderson, Newcomb Lake, Lower Works reservoir, Chain Lakes, Goodenow Pond, Goodenow River reservoir, South Pond, Clear Pond, Slim Pond, Ackerman Pond, Perch Pond, Trout Pond, Lake Harkness, Shedd Lake, First Sergeant Pond, Third Sergeant Pond, Plumley

Pond, Moose Pond, and Cary Pond. The total storage to be furnished by the entire system of reservoirs is placed at 18,419,781,600 cubic feet. The total cost of the proposed reservoirs was placed by Mr. Benedict at about $265,000, or, including the diversion canal and improvements at Long Lake, at a total of about $460,000. The dams

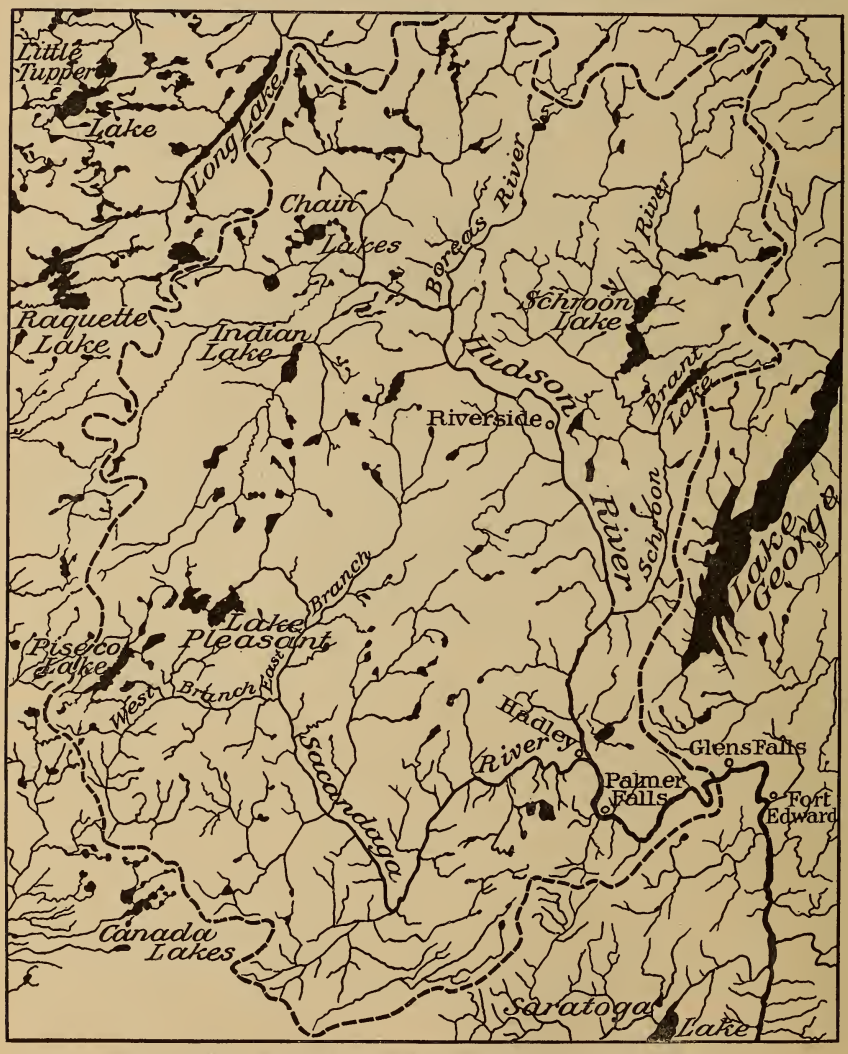


Fig. 1.—Map of drainage area of Hudson River above Glens Falls.

proposed were to be constructed of timber, very much after the plan of the timber dams still constructed by the lumbermen in this region, as shown on Pl. III.[1]

[1] For further particulars of Mr. Benedict's reservoir system, see Report on a Survey of the Waters of the Upper Hudson and Racket Rivers in the Summer of 1874, with Reference to Increasing the Supply of Water for the Champlain Canal and Improving the Navigation of the Hudson River, by F. N. Benedict, Ass. Docs. (1875), Vol. I, No. 6, p. 85.

A. LUMBERMAN'S DAM ON CEDAR RIVER

B LUMBERMAN'S DAM ON INDIAN RIVER

In 1874, when Mr. Benedict prepared his report, the demands for water upon Hudson River were far less extensive than at present, and even in 1882 the total water power of the stream was, according to the statistics of the Report on the Water Power of the United States, Tenth Census, only 12,894 horsepower, while in 1895 the total horsepower was 43,481. Taking into account additional wheels set in the last two years, as well as the extensive development of the Hudson River Power Transmission Company now in progress 3 miles below Mechanicville, it is probable that early in 1898 there will be wheels set on Hudson River capable of furnishing, at full capacity, not far from 55,000 horsepower. This great development has led to a very strong demand in the last few years for increased flow during the low-water period.

RECENT INVESTIGATIONS.

In 1895 a survey of the upper Hudson Valley was authorized with the view of determining what lakes and streams may be improved, and the water stored and diverted, in order to provide for the enlargement of Champlain Canal; for restoring to the water of Hudson River at or below Glens Falls the water diverted therefrom for canal purposes, and for improving the navigation of the lower Hudson River. The Hudson River naturally divides into two sections—the upper and the lower—at the Troy dam, which is the head of the lower or tidal section. The proposed reservoirs are all in the upper section, above Troy.

When one considers the scope of the investigation it may be readily seen that the studies must necessarily be of rather wide range. Special consideration should be given the following topics:

(1) The area of the several subdivisions of the drainage area, together with the locations and extent of the reservoir sites, and the total area from which the run-off can be controlled.

(2) The rainfall and mean temperature of the tributary region, as well as its physical characteristics, the relative amounts of timber and cleared area, etc.

(3) The actual run-off of the stream from the known area for a series of years, and a deduction therefrom by comparison with the rainfall and temperature records of the amount which may be stored in the year of minimum rainfall; also the relation which the run-off in the year of minimum precipitation bears to what may be expected in the average year, and a deduction therefrom of the proper height of flow lines for full-capacity development.

(4) The areas of the reservoirs and the losses therefrom by evaporation which may be reasonably expected, with the amount of effective storage which may be gained by the reservoir system when developed to full capacity.

(5) The amount of water now diverted for the use of Champlain

Canal, and the amount to be diverted for such use when the enlargement is completed; also the proper method of managing the system of reservoirs in order to secure the best results to the canal, the navigable section, and the water power.

(6) The amount of water power now in use on the stream and the effect of the present and future diversion.

(7) The regimen of the tidal section, and the effect of the unregulated fresh-water flow and of the construction of the system of impounding reservoirs.

(8) The cost of the reservoirs and the relation which the actual cost bears to the amount of storage gained. This latter element determines the commercial feasibility of the project.

RESERVOIR SITES ON SACUNDAGA, MAIN HUDSON, AND SCHROON RIVERS.

The surveys, so far as carried, indicate that economical reservoirs controlling the entire drainage area to full capacity in the year of minimum rainfall may be constructed in the Sacundaga, main Hudson, and Schroon valleys, as shown in the following paragraphs.

The Sacundaga River has, as already stated, a total drainage area above its mouth at Hadley of 1,040 square miles. The catchment areas of reservoir sites on Sacundaga River, in square miles, are as follows:

Catchment areas of reservoir sites on Sacundaga River.

	Square miles.
Lakes Pleasant and Sacundaga	45
Piseco Lake	55
Arietta flow	40
Miscellaneous	50
Total	190

The main Hudson or North River has a total drainage area above Hadley, not including Schroon River, of 1,092 square miles. Of this area the portions shown below may be developed to full capacity in the year of minimum rainfall:

Catchment area of reservoir sites on main Hudson River.

	Square miles.
Thirteenth Pond	14
Chain Lakes	58
Catlin Lake	25
Lakes Rich, Harris, and Newcomb, and the Goodenow flow	83
Lake Henderson	18
Lake Sanford and the Tahawus flow	67
Boreas River and Boreas Pond	45
Cedar River	58
Indian Lake	146
Total	514

Schroon River has a total drainage area above its mouth of 550 square miles. The topography of the Schroon area is such as to admit of two distinct lines of treatment—either to construct one large dam at Tumblehead Falls, about a mile below South Horicon, or to construct a series of 16 to 18 small dams at various points in the area. In either case it is possible to control substantially the full flow of the 502 square miles above Tumblehead Falls, and the decision of which is better will turn chiefly on the question of relative cost, the estimate taking into account the fact that it will cost much more to operate a large number of reservoirs than to operate one.

Catchment area of small reservoirs on Schroon River.

	Square miles.
Minerva Brook at Olmsteadville	43.4
Hewett Pond	2.5
Loon Lake	11.6
Friend Lake	4.9
Elk Lake	15.9
Clear Pond	2.3
New Pond	1.7
Deadwater Pond	18.9
Hammond Pond	11.4
Dudley Pond	3.9
Overshot Pond	4.9
Paradox Lake	31.6
Paragon Lake	5.6
Crane Pond	7.2
Pharaoh Lake	8.3
Brant Lake	38.7
Valentine Pond	6.7
Schroon Lake at Starbuckville	259.2
Total	478.7

The area between Starbuckville and Tumblehead Falls not available with the system of small reservoirs is 23.3 square miles.

The total controllable area of the upper Hudson, with the system of small reservoirs in the Schroon Valley, is as follows:

Total catchment area of upper Hudson River.

	Square miles.
Sacundaga Valley	190
Hudson above Hadley	514
Schroon Valley	479
Total	1,183

With one large reservoir in Schroon Valley the catchment area is increased to 1,206 square miles.

The system of small reservoirs outlined in the foregoing is estimated to store 15,330,000,000 cubic feet, at a cost of $1,172,500; hence the

cost per million cubic feet stored becomes $76.48. These figures, however, do not take into account the annual cost of maintenance and operation, which may be placed at $30,000 per year, and capitalized at 5 per cent is equivalent to a permanent investment of $600,000. Adding $600,000 to $1,172,500 gives a total permanent investment of $1,772,500.

A general estimate of the cost of the single large reservoir in Schroon Valley shows that with a dam at Tumblehead Falls 59 feet in height there would be impounded 15,925,000,000 cubic feet. The preliminary estimate indicates a total cost of $840,000, and a later survey indicates about $1,000,000. The final revision of the estimate on completion of the investigation may show a somewhat larger figure than this. Even if the cost were to be $1,100,000, it would still be exceedingly cheap storage, the cost for 15,925,000,000 cubic feet being on this basis only $69.14 per million cubic feet stored.

The dam at Tumblehead Falls would be located just below the outlet of Brant Lake, the elevation of the water surface of which is 801 feet. The flow line of the proposed reservoir has been placed at an elevation of 840 feet, thus giving a depth of 39 feet over the surface of Brant Lake, a depth of 33 feet over the surface of Schroon Lake, and a depth of 20 feet over Paradox Lake. With the reservoir full or nearly full, there would be continuous navigation from the head of Brant Lake to the head of Paradox Lake of about 35 miles. The villages of South Horicon, Bartonville, Starbuckville, and parts of Pottersville and Chester are within the flow line of this reservoir.

As another large reservoir to be built on the head waters of the Hudson, Indian Lake reservoir may be mentioned. As shown on page 128, the total controllable area at this lake is 146 square miles, which is capable of furnishing, in the year of minimum run-off, 4,468,000,000 cubic feet. To provide this storage, a dam raising the water surface 23 feet above the present dam is required. The storage of the present dam 10 feet in height is estimated at 800,000,000 cubic feet. In the spring of 1897 a private company, known as the Indian River Company, was organized to construct the Indian River reservoir. This company proposes to construct a masonry and concrete dam to the height of 23 feet above the old timber dam. The work is now in process of construction. The clearing of the margins of the lake includes the cutting of about 1,160 acres of timber.

The Indian River Company was the owner of considerable land bordering on and in the vicinity of Indian Lake. In consideration of the transfer of townships 15 and 32 of the Totten and Crossfield purchase to the State forest preserve board, that board has, in effect, purchased the dam in process of construction, which, with the clearing of the margins, is estimated to cost about $100,000. The forest preserve board stipulated that the superintendent of public works

have the right to draw water from the reservoir when necessary for the supply of Champlain Canal, the balance of the storage to be used by the Indian River Company for increasing the low-water flow of Hudson River for the benefit of the water power. At a total cost of $100,000 the cost per million cubic feet stored becomes $22.38. Taking into account the quantity of water stored at Indian Lake, this must be considered a very cheap reservoir.[1]

Piseco Lake may also be referred to as another large reservoir which may be constructed on the upper Hudson at low cost. It is estimated that a storage of 1,725,000,000 cubic feet may be made, at an expenditure of $70,000, or at an average cost per million cubic feet stored of $40.

Without going further into detail, the following may be given as the approximate storage of the entire upper Hudson system, worked out to date.[2]

Approximate storage of upper Hudson River.

	Cubic feet.
Storage of Sacundaga and main Hudson River drainage areas, not including Boreas River reservoir, Boreas Pond, Indian Lake, and Piseco Lake	14,364,000,000
Boreas River reservoir and Boreas Pond	1,111,000,000
Indian Lake	4,468,000,000
Piseco Lake	1,725,000,000
Schroon Valley	15,925,000,000
Hadley	4,000,000,000
Conklinville	4,000,000,000
Total	45,593,000,000

This storage is considered sufficient, in conjunction with the natural flow of the unregulated portion of the river, to maintain at Mechanicville a flow of at least 4,500 cubic feet per second during the entire year.

In addition to the reservoirs named above, the general investigations indicate that there is, possibly, an opportunity to make a large reservoir on Sacundaga River by the erection of a dam about 20 feet in height at Conklinville, where there is a reach of river extending 24 miles to Northville. The available storage of such a reservoir is taken at about 4,000,000,000 cubic feet.

There is also an opportunity to construct on the main Hudson at Hadley, just above the mouth of the Sacundaga, another reservoir of about 4,000,000,000 cubic feet capacity, at a point where the natural conditions for constructing such a reservoir are considered very good. At the site of the proposed dam the river shows a granitic rock bottom

[1] This dam was completed in 1898.

[2] For full details the reader is referred to the original reports on the upper Hudson storage surveys, in the Annual Reports of the State Engineer and Surveyor for the fiscal years ending September 30, 1895 and 1896.

with precipitous banks nearly 40 feet in height and about 100 feet apart. The material for a permanent stone dam exists in the vicinity, with an opportunity to construct a wasteway over natural rock at one side.

Inasmuch as all the storage except that of the Sacundaga area would pass through the Hadley reservoir, its construction would simplify the management of the system very greatly. In the summer season, as long as there is any storage above to be drawn upon, this reservoir could be kept nearly full and just the right quantity drawn out from day to day to keep the river at the assumed flow of 4,500 cubic feet a second at Mechanicville.

EFFECT OF PROPOSED STORAGE ON RIVER FLOW.

The foregoing quantities of storage have been fixed upon on the basis that the water yield of the year of minimum stream flow will furnish a storage of at least 12 inches, the flow line of the reservoirs themselves being located with reference to holding back 13.5 inches. If, however, one examines the tables of run-off of the Hudson at Mechanicville, given in Part I of this paper, on page 82, and of precipitation in the watershed, given on the next page, it is seen that much greater yields can be expected in an average year. From this point of view, it may be asked, Why not make the reservoirs somewhat larger than merely sufficient for the wants of the year of minimum flow and carry some water over from one year to another, thus more nearly attaining an absolute regulation of the river—not for a single year, but for a series of years? The chief objection to this method of procedure is that experience with other large reservoir systems is against other than a moderate development on this line, it having been repeatedly found that however high the flow line, reservoirs are likely to be nearly empty at the beginning of the storage period of the minimum year. Experience indicates that the rainfall and stream flow move in cycles, there being in each cycle several successive years of flow above the average. The demands for water tend to increase during the years of plenty, until those in charge apparently forget there will ever be a deficiency. The best practice, therefore, is to locate the flow line with reference to about the minimum yield, thus forcing an economy in the use of water from the beginning. By proceeding in this way provision may be made for carrying over moderate quantities of water from the latter end of the year more effectually than in any other way.

A. THE GEORGE WEST PAPER MILL, ON HUDSON RIVER AT HADLEY, NEW YORK.

B THE HUDSON RIVER PULP AND PAPER COMPANY'S MILLS AT PALMER FALLS, ON HUDSON RIVER, NEW YORK.

Mean precipitation on the upper Hudson watershed.

[In inches.]

Month.	Albany.	Glens Falls.	Keene Valley.	Mean of Albany, Glens Falls, and Keene Valley.	Western Massachusetts.	Northern Plateau	Lowville Academy.	Johnstown Academy.	Cambridge Academy.	Fairfield Academy.	Granville Academy.	Mean of all.
December	2.71	3.19	2.75	3.01	4.31	3.57	2.14	2.91	2.36	2.78	2.48	2.92
January	2.75	3.16	3.00	3.03	3.36	3.88	2.35	3.30	3.36	2.69	2.08	2.99
February	2.49	3.03	2.22	2.64	2.83	3.60	2.43	2.86	2.61	2.06	1.42	2.56
March	2.72	2.72	2.24	2.50	2.94	2.52	1.78	3.63	2.12	2.36	1.74	2.48
April	2.80	2.15	2.09	2.14	2.02	2.39	1.91	2.93	3.36	2.53	2.13	2.43
May	3.62	3.10	3.05	3.14	3 17	4 46	2.79	3.45	3.65	3.04	3.47	3.38
	17.09	*17.35*	*15.35*	*16.47*	*18.63*	*20.42*	*13.40*	*19.08*	*17.46*	*15.46*	*13.32*	*16.76*
June	4.07	2.83	2.89	2.99	3.24	3.88	3.42	4.20	4.66	4.29	3.21	3.67
July	4.29	3.25	3.61	3.53	3.44	3.83	3.67	4.01	3.91	4.21	3.63	3.78
August	3.96	4.17	4.21	4.20	3.91	5.07	2.85	3.14	3.98	3.66	2.97	3.79
	12.32	*10.25*	*10.71*	*10.75*	*10.59*	*12.78*	*9.94*	*11.35*	*12.55*	*12.16*	*9.81*	*11.25*
September	3.43	2.96	3.00	3.13	3.51	3.57	2.84	2.87	3.27	3.08	2.67	3.12
October	3.58	2.36	2.49	2.60	3.41	3.06	3.29	3.20	3.60	3.56	2.90	3.15
November	3.08	3.24	3.56	3.26	2.84	3.46	2.94	3.33	3.29	2.46	2.88	3.11
	10.09	*8.56*	*9.05*	*8.99*	*9.76*	*10.09*	*9.07*	*9.49*	*10.16*	*9.11*	*8.45*	*9.38*
Total	39.50	36.16	35.11	36.22	38.98	43.29	32.41	39.92	40.17	36.73	31.58	37.39

The figures in the above table are obtained by averaging the results obtained at Albany from 1825 to 1895; at Glens Falls, from 1879 to 1895; at Keene Valley, from 1879 to 1895; in western Massachusetts, from 1887 to 1895; in Northern Plateau, from 1889 to 1895; at Lowville Academy, from 1827 to 1848; at Johnstown Academy, from 1828 to 1845; at Cambridge Academy, from 1827 to 1839; at Fairfield Academy, from 1828 to 1849; at Granville Academy, from 1835 to 1849; the mean of Albany, Glens Falls, and Keene Valley, from 1879 to 1895. Although the foregoing figures are here given in detail, later studies indicate that the mean rainfall of the Northern Plateau as defined by the State meteorological bureau is the best rainfall record to apply to the upper Hudson area.

The proposed regulation of Hudson River, as thus far planned, is to be arranged on the basis of maintaining a flow of at least 4,500 cubic feet per second at Mechanicville, where, as has been seen, the drainage area is 4,500 square miles, such a regulation being equivalent to producing at Mechanicville a constant flow of 1 second-foot per square mile. The relation of such regulated flow to the natural unregulated flow may be seen by studying the diagrams of flow of Hudson River at Mechanicville given in Part I, on page 81.

As regards the change in the regimen of the stream due to storage, it may be remarked that the reservoirs have been designed on the basis of giving to the stream at least 0.5 inch on the drainage area per month. This amounts to 0.45 cubic foot per second per square mile for a month of thirty days; it is not, however, intended to state that the entire river will ever be as low as 0.45 cubic foot per second per square mile, or, what is the same thing, as low as 2,025 cubic feet per second at Mechanicville, but only that those tributary streams on which the storage reservoirs are located may be down to this figure. With 0.45

cubic foot per second per square mile always flowing away from the controlled drainage area, the natural flow of the unregulated portion will usually furnish an additional amount sufficient to keep the river, during the storge period, up to nearly the assumed 4,500 cubic feet at Mechanicville; or in case of extreme low water in winter other reservoirs may be relied upon to assist in the manner already pointed out.

On the basis of 12 to 14 inches available storage, there may be, with 0.5 inch per month always going to the stream, a possible total requirement for the year of from 15 to 18 inches.

The table in Part I of this paper, on page 82, shows that the total flow for the water year 1895 was only 17.46 inches, or in that year there might have been a shortage if the reservoir system had been in operation of perhaps 0.5 inch. Any such shortage would necessarily have been carried over from the year 1894, when, in November, there was a run-off of 1.58 inches. Allowing 0.5 inch to the stream, from the November rainfall alone there would have been 1.08 inches remaining in the reservoirs to be carried over to 1895.

SUMMARY.

In conclusion, it may be said that it is entirely feasible to construct a system of reservoirs in the upper Hudson Valley, and such system may be designed with reference to the full capacity storage of at least 1,300 square miles of area, or 47 per cent of the total area above Glens Falls. Such control would result in the material reduction of floods at Glens Falls and other points.

The proposed total storage of 45,593,000,000 cubic feet would maintain 4,500 cubic feet per second flow, as well as supply the other necessary demands, in the driest season of the gaging period. The discharge measurements show that whereas the minimum unregulated flow at Glens Falls is as low as 900 cubic feet per second for a monthly mean, with the storage carried out, the probable monthly mean flow at Glens Falls will be at least 3,000 to 3,600 cubic feet per second. The minimum regulated flow of 4,500 cubic feet per second at Mechanicville will increase the low-water depth in Hudson River at Albany about 1.5 feet.

The diversion of water for the use of Champlain Canal is an injury to the water power at Glens Falls and lower points on the river. Since water power is much cheaper than steam power, the taking of the water of the river away from the manufacturers is a serious matter. In the fourteen years from 1882 to 1895 the use of water power on Hudson River has increased from a total of 12,894 net horsepower in 1882 to 43,481 net horsepower in 1895, an increase of 237 per cent.

The upper Hudson storage system is estimated to cost from $60 to $70 per million cubic feet stored, a sum considerably less than the cost of many other systems.

A. GLENS FALLS PAPER MILLS AT FORT EDWARD, NEW YORK.

B. DAM OF THE HUDSON RIVER POWER TRANSMISSION COMPANY DURING CONSTRUCTION, OCTOBER, 1897.

DEVELOPMENT OF WATER POWERS.

POWER DEVELOPMENT AT NIAGARA FALLS.

The possibility of water-power development at Niagara Falls has attracted attention for many years, the first utilization there having been made in 1725, when the French erected a sawmill near the point where the Pittsburg Reduction Company's upper works now stand for the purpose of supplying lumber for Fort Niagara. Between 1725 and the early years of the present century little is known of the use made of Niagara Falls power further than that sawmills were in operation there during the whole period. In 1805, however, Augustus Porter built a sawmill on the rapids, and in 1807 Porter & Barton erected a gristmill. In 1817 John Witmer built another sawmill at Gill Creek, and in 1822 Augustus Porter built a gristmill along the rapids above the falls. From that year to 1885, when the lands along the river were taken for a State park, a considerable amount of power was developed by a canal which took water out of the river near the head of the rapids and followed along the shore nearly parallel with the bank of the river. Mills were built between this canal and the river, and a part of the 50-foot fall between the head of the rapids and the brink of the American Falls was thus utilized. A paper mill was built on Bath Island at an early date.

In 1842 Augustus Porter, one of the principal mill owners at Niagara Falls, proposed a considerable extension of the then existing system of canals and races, and in January, 1847, in connection with Peter Emslie, he published a formal plan which became the subject of negotiations with Walter Bryant and Caleb S. Woodhull. An agreement was finally reached by which they were to construct a canal and receive a plot of land at the head of the canal, having a frontage of 425 feet on Niagara River, together with a right of way 100 feet wide for the canal along its entire length of 4,400 feet, and about 75 acres of land near the terminus, having a frontage on the river below the falls of nearly a mile. The canal constructed under this agreement passes through what is now the most thickly settled part of the city of Niagara Falls.

Ground was broken by Messrs. Bryant & Woodhull in 1853 and the work carried on for about sixteen months, when it was suspended for lack of funds. Nothing further was done until 1858, when Stephen Allen carried the work forward for a time; later, in 1861, Horace H. Day took up the matter and completed a canal 36 feet wide, 8 feet deep, and 4,400 feet long, by which the water of the upper river was brought to a basin near the brink of the high bluff of the lower river and at an elevation of 214 feet above the lower river. Upon the margin of this basin various mills have been constructed, to the wheels of which water is conducted from the canal and discharged through the bluff into the river below. The first mill built on this hydraulic canal was a small gristmill, erected by Charles B. Gaskill in 1870 on the site of the present large flouring mill of the Cataract Milling Company.

NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

In 1877 the hydraulic canal and all its appurtenances were purchased by Jacob F. Schoellkopf and A. Chesbrough, of Buffalo, who organized the Niagara Falls Hydraulic Power and Manufacturing Company, of which Mr. Schoellkopf is still president. The following is a list of companies either now supplied or to be supplied with power by the Niagara Falls Hydraulic Power and Manufacturing Company.

Power furnished by Niagara Falls Hydraulic Power and Manufacturing Company.

WATER POWER.

Company.	Business.	Horse-power.
Central Milling Co	Flouring mill	1,000
N. Wood Paper Co	Paper and pulp	500
Schoellkopf & Mathews	Flouring mill	900
Pettebone Cataract Manufacturing Co	Paper and pulp	2,000
Cataract Milling Co	Flour	400
Niagara Falls Waterworks		200
Thomas E. McGarigle	Machine shop	25
Cliff Paper Co	Paper and pulp	2,500
Total		7,525
ELECTRIC POWER.		
Pittsburg Reduction Co	Aluminum	3,500
Niagara Falls and Lewiston R. R. Co		400
Cliff Paper Co	Paper and pulp	300
Lewiston and Youngstown R. R. Co		200
Buffalo and Niagara Falls Electric Light and Power Co.	Light and power	600
Niagara Falls Brewing Co		150
Rodwell Manufacturing Co	Silver plating, etc.	75
Sundry small customers in Niagara Falls.		100
Francis Hook and Eye Co	Hooks and eyes	15
Kelly and McBean Aluminum Co	Aluminum	15
The National Electrolytic Co		1,000
Total		6,355
MECHANICAL POWER FURNISHED ON SHAFT.		
Oneida Co., Limited	Silver-plated ware and chains.	300
Carter-Crum Co	Check books	60
Total		360
Grand total		14,240

POWER HOUSE OF THE NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

The contract made in 1852 between Augustus Porter, Walter Bryant, and Caleb J. Woodhull only conveyed lands to the edge of the high bank of Niagara River, but did not include the talus or slope between the edge of the high bank and the river, and only granted the right to excavate 100 feet down the face of the bank. In 1852, when this contract was made, the use of water power under higher heads than 100 feet was, so far as the United States was concerned, entirely unknown. Until recently the mills at Niagara Falls have not attempted to use more than 50 or 60 feet head; hence it resulted that although the capacity of the Niagara Falls Hydraulic Power and

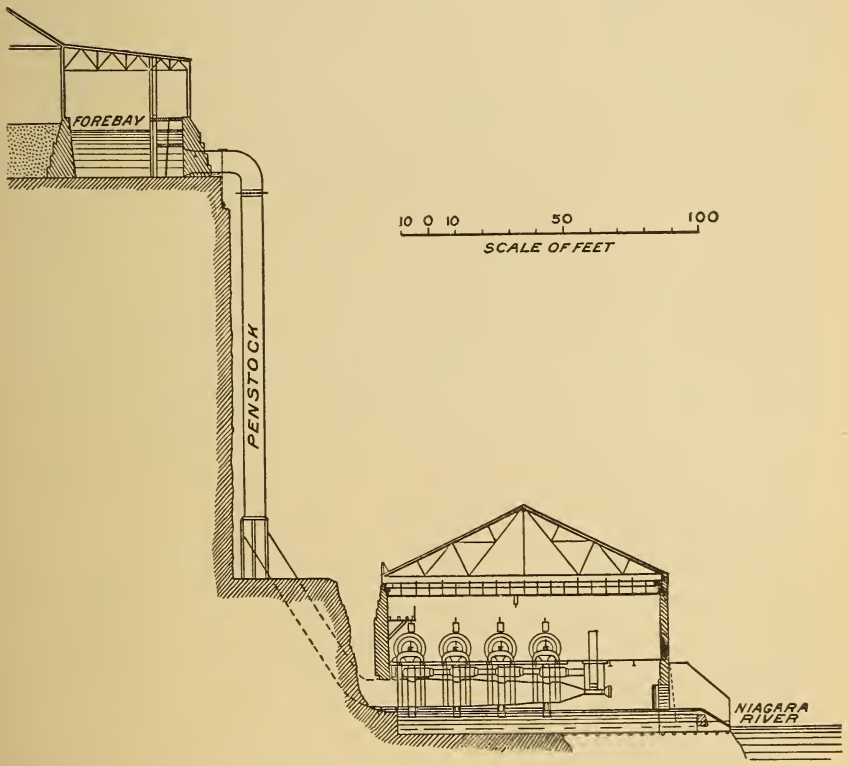


FIG. 2.—General plan of development of the Niagara Falls Hydraulic Power and Manufacturing Company.

Manufacturing Company's canal, as at first constructed, was sufficient, by development of the whole head, to produce about 15,000 horsepower, under the original agreements its capacity was exhausted when about 7,000 horsepower was produced.

In 1892 the Niagara Falls Hydraulic Power and Manufacturing Company began an enlargement and improvement of its canal. The plan adopted was to widen the original channel at one side to 70 feet, and make the new part 14 feet deep. This work is cut entirely through rock, below the water line. The enlargement of one side was completed in 1896. The canal as enlarged to date has a capacity

of about 3,000 cubic feet per second, giving, under present conditions, a total of from 40,000 to 50,000 horsepower, the cross section being about 400 square feet.

This company has a grant from the State of the right to draw from Niagara River as much water as can be taken through a canal 100 feet wide and 14 feet deep. Work on further enlargement is now in progress, and it is expected, within a year or two, to have a total of about 675 feet area of water section.

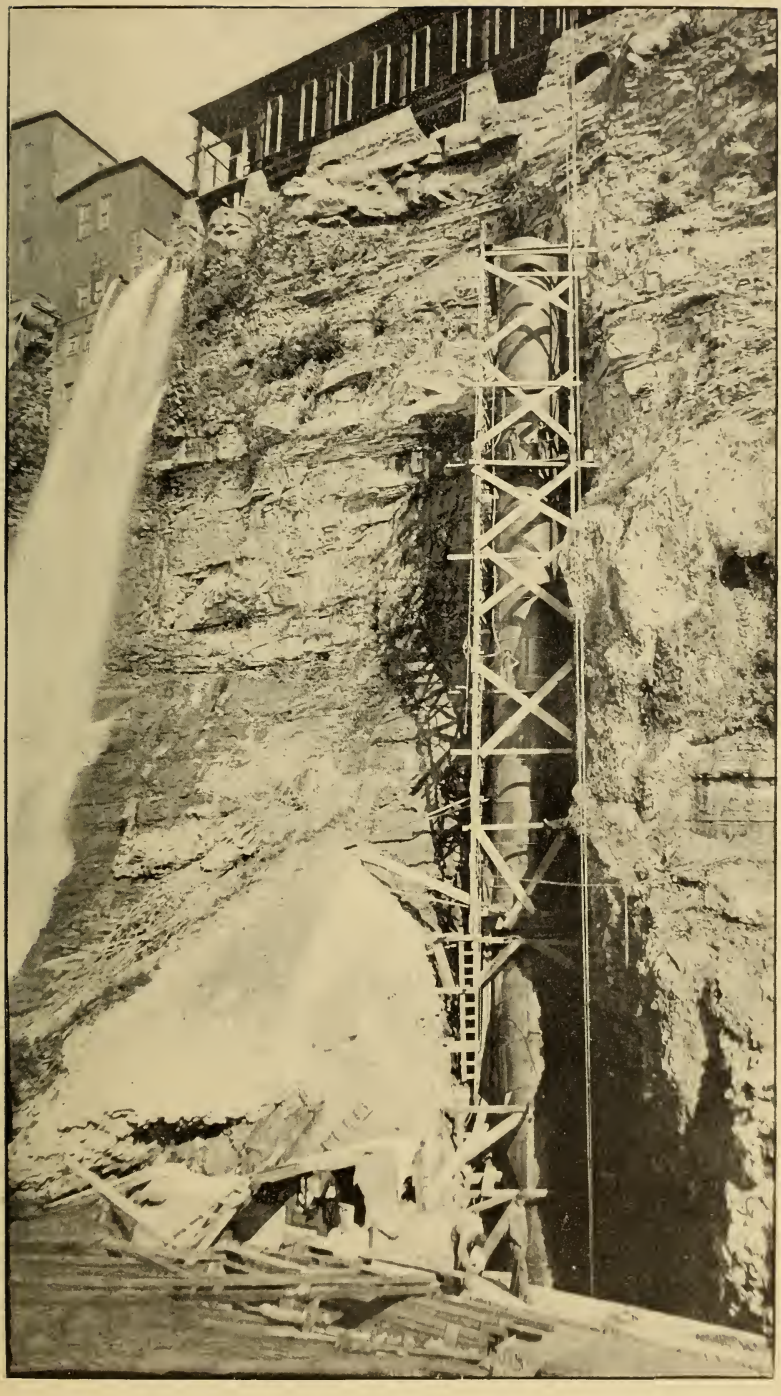
To July 1, 1897, about 100,000 cubic yards of material had been taken out at a cost of $250,000, the average cuttings in the original canal from the surface of the ground to the surface of the water being about 8 feet.

The development now in process by this company is very interesting. A bulkhead is located at the top of the high bank with a fore bay back of it connected with the main hydraulic canal by a short-branch canal. From the fore bay a large penstock leads vertically down the cliff to a power house located directly on the shore of the lower river. In this power house horizontal turbine water wheels are placed, with dynamos directly connected, the power therefrom being transmitted either to the mills on the bluff above or to establishments at a distance. (See Pl. VII and fig. 2.) This company expects soon to transmit several thousand horsepower to Buffalo.[1] Without taking into account the cost of water in the canal, the cost of the development of power in the way in which it is now being developed by this company may be placed at $35 per horsepower.

NIAGARA FALLS POWER COMPANY.

The Niagara Falls Power Company has developed an extensive plant on quite different lines from that of the Niagara Falls Hydraulic Power and Manufacturing Company. In 1883 to 1885 Thomas Evershed, who was at that time division engineer of the western division of the New York State canals, was called on to survey Niagara Falls Park Reservation, as provided for by act of the legislature. This led Mr. Evershed to spend considerable time at Niagara Falls, during which he conceived the project of constructing a tunnel to begin at the level of the lower river and extend under the city of Niagara Falls for a distance of about 2½ miles. (See fig. 3.) This tunnel, as proposed, was to be generally parallel to the Niagara River, but at some little distance from it. At its head and at various points along the river from above Port Day it was proposed to construct branch canals

[1] For further details of the Niagara Falls Hydraulic Power and Manufacturing Company, see (1) Power development of Niagara Falls, other than that of the Niagara Power Company, by W. C. Johnson: Trans. Engineers' Society of Western New York, Vol. I, No. 6 (Feb. 3, 1896); (2) Niagara Falls Hydraulic Power and Manufacturing Company's new work, by Orrin E. Dunlap: Electrical Engineer, Vol. XX (Dec. 4, 1895); (3) Old hydraulic power plant at Niagara Falls transformed for electrical transmission, by Orrin E. Dunlap: Western Electrician, Vol. XIX (Dec. 5, 1896); (4) Pulp mill of the Cliff Paper Company of Niagara Falls, New York, by W. C. Johnson: Trans. Am. Soc. Civil Eng., Vol. XXXII (Aug., 1894).



PENSTOCK OF THE NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

connecting with the river and through which water could be taken, to be discharged upon turbine wheels placed in vertical wheel pits and connected with the tunnel at various points.

The Niagara River Hydraulic Tunnel, Power and Sewer Company of Niagara Falls was incorporated in 1886 for the purpose of constructing and operating, in connection with Niagara River, a hydraulic tunnel or subterranean sewer for public use in the disposal of sewage and drainage and for furnishing hydraulic power for manufacturing purposes in the town of Niagara Falls. In consideration of the public service of sewerage and drainage, this company was authorized to acquire land by condemnation.

The general plan of development is described by Mr. Evershed in

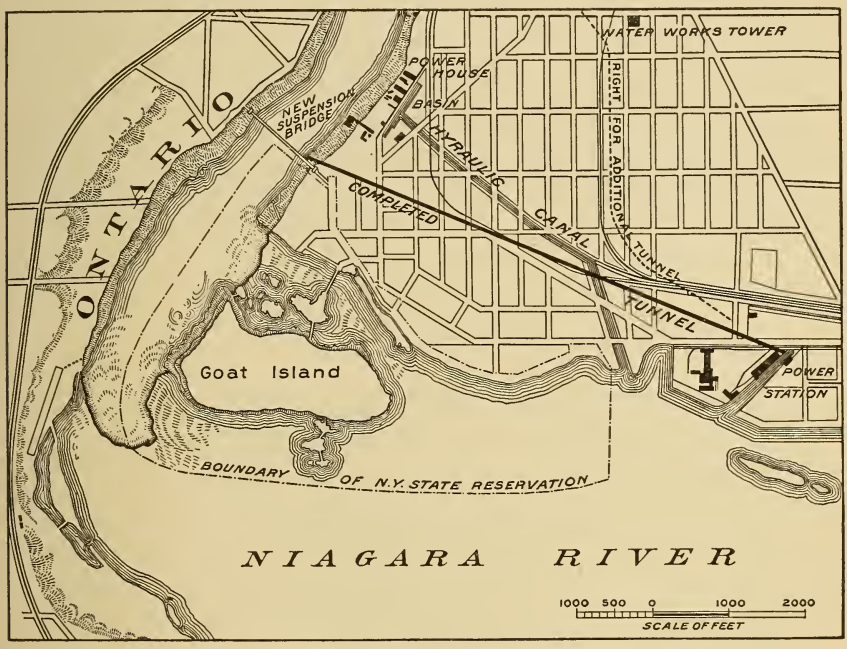


FIG. 3.—Map of Niagara Falls and vicinity, showing location of the great tunnel. (From Cassier's Magazine, Vol. VIII, p. 183.)

a report made July 1, 1896, in which he states that the main tunnel would begin at a point on the lower river immediately north of the State reservation, with its mouth as low as high water below the falls would permit. From this point to half a mile above Port Day it should have a rise of 1 foot in 100, or 52.8 feet per mile, and a section above Port Day equivalent to a circle 24 feet in diameter, the tunnel gradually diminishing in size in accordance with the number of mills emptying tail-water into it, until at the upper end it would have the same area of cross section as the connecting cross tunnels.[1]

The matter remained in abeyance until 1889, when the Niagara Falls

[1] See pamphlet, Water Power at Niagara Falls, prospectus of the Niagara River Hydraulic Tunnel, Power, and Sewer Company (1886).

Power Company was organized to carry out, in effect, Mr. Evershed's plan. The actual work of construction was undertaken by the Cataract Construction Company, composed of William B. Rankine, Francis Lynde Stetson, Pierpont Morgan, Hamilton McK. Twombly, Edward A. Wickes, Morris K. Jesup, Darius Ogden Mills, Charles F. Clarke, Edward D. Adams, Charles Lanier, A. J. Forbes-Leith, Walter Howe, John Crosby Brown, Frederick W. Whirtridge, William K. Vanderbilt, George S. Bowdoin, Joseph Larocque, John Jacob Astor, and Charles A. Sweet. This company has modified the original plans in some particulars, although the general scheme has been carried out.

The plan finally determined on comprised a surface canal 250 feet in width at its mouth on the river, 1¼ miles above the falls, extending inwardly 1,700 feet, with an average depth of 12 feet, and computed to furnish water sufficient for the development of about 120,000 horsepower. The masonry walls of this canal are pierced at intervals with inlets, guarded by gates. Some of these are used to deliver water to tenants who construct their own wheel pits and set their own wheels, while 10 of them are arranged on one side of the canal for the purpose of delivering water to the wheel pit of the Niagara Falls Power Company's power station, where dynamos, placed at the top of turbine vertical shafts, generate electricity for transmission. The wheel pit at the power station is 178 feet in depth and connected with the main tunnel by a short cross tunnel. The main tunnel as carried out has a maximum height of 21 feet and a width of 18.82 feet, making a net section of 386 square feet. The slope of this tunnel is 6 feet to the thousand.

The most careful consideration was given to the subject of the turbines to be used, as well as to the question of power transmission. In 1890 Edward D. Adams, who was then president of the company, established an International Niagara Commission, with power to offer $20,000 in prizes. This commission consisted of Sir William Thomson (now Lord Kelvin), Dr. Coleman Sellers, Lieut. Col. Theodore Turretini, Prof. E. Mascart, and Prof. W. C. Unwin. Inquiries concerning the best-known methods of development and transmission of power in England, France, Switzerland, and Italy were made, and competitive plans were received from twenty carefully selected engineers and manufacturers of power plants in England, Europe, and America. These plans were submitted to the commission, which awarded prizes to those considered worthy. The most important result was the selection of the designs of Faesch and Piccard, of Geneva, for turbines computed to yield 5,000 horsepower each. Three wheels have been built from these designs and are now in place and regularly operated.

Without going into details of the electrical work, it may be stated that the Niagara Falls Power Company adopted the two-phase alternating current system as best adapted to its work. In the dynamos employed the field magnet revolves instead of the armature. As

A. POWER HOUSE OF THE NIAGARA FALLS POWER COMPANY.

B. OUTLET OF TUNNEL OF THE NIAGARA FALLS POWER COMPANY

advised by the company's electrical engineer, Prof. George Forbes, of London, three such dynamos, of 5,000 horsepower each, constructed by the Westinghouse Company, of Pittsburg, have been installed. During the summer of 1896 a transmission line was constructed from Niagara Falls to Buffalo, and since November of that year some of the street railways in Buffalo have been operated electrically by power from Niagara Falls.

According to a statement of William B. Rankine, secretary of the Cataract Construction Company, the power furnished or contracted for by the Niagara Falls Power Company July 1, 1897, was as follows:

Power furnished by the Niagara Falls Power Company.

HYDRAULIC POWER.

Company.	Business.	Horse-power.
Niagara Falls Paper Company	Paper	7,200
ELECTRIC POWER.		
Pittsburg Reduction Company	Aluminum	3,050
The Carborundum Company	Abrasives	1,000
Acetylene Light, Heat, and Power Company	Calcium carbide	1,075
Buffalo and Niagara Falls Electric Light and Power Company.	Local lighting	500
Walton Ferguson	Chlorate of potash	500
Niagara Electro-Chemical Company	Peroxide of sodium	400
Buffalo and Niagara Falls Electric Railway	Local railway	300
Niagara Falls and Suspension Bridge Railway Company.*a*	do	250
Buffalo Street Railway Company	22-mile transmission	1,000
Acetylene Light, Heat, and Power Company *b*	Calcium carbide	4,000
Mathieson Alkali Works *c*	Soda ash	4,000
Buffalo Street Railway Company		1,000
Buffalo General Electric Company *d*	Lighting	3,000
The Carborundum Company *e*	Abrasives	1,000
Niagara Falls Water Works Company		45
Power City Foundry and Machine Company		25
Albright and Wilson	Electro-chemicals	400
Total hydraulic power sold at Niagara Falls		7,200
Total electric power sold at Niagara Falls		14,545
Total electric power sold at Buffalo		5,000
Total		26,745

a All from October 1, 1896.
b From delivery, say, November 1, 1897.
c From June 1, 1897.
d From November 15, 1897.
e From June 1, 1897.

Recapitulation of the total power in use or furnished from Niagara Falls January 1, 1898, shows the following amounts:

	Horsepower.
Hydraulic power:	
Niagara Falls Power Company	7,200
Niagara Falls Hydraulic Power and Manufacturing Company	7,525
Electric power:	
Niagara Falls Power Company	19,545
Niagara Falls Hydraulic Power and Manufacturing Company	6,355
Mechanical power:	
Niagara Falls Hydraulic Power and Manufacturing Company	360
Total	40,985

The large demand for power from the Niagara Falls Power Company has necessitated the enlargement of the wheel pit and power house to more than three times their present capacity. The work upon this enlargement, sufficient to provide 35,000 additional horsepower, has been in progress since June, 1896, and is now approaching completion. With the completion of this extension the Niagara Falls Power Company will have available 50,000 horsepower; a portion of the increased power was ready for delivery January 1, 1898.

The 50,000 horsepower developed when the present extension is completed represents but one-half of the capacity of the present tunnel. This company has further secured the right of way for a second discharge tunnel, so that when the demand for power shall render it necessary the present plant may be duplicated, thus furnishing 200,000 horsepower in all. In addition to this large development on the American side, the Canadian Niagara Power Company, an allied corporation, now holds from the Canadian government an exclusive franchise granting to it the right to develop on the Canadian side at least 250,000 horsepower. The total possible power proposed to be developed in the future at Niagara Falls is about as follows:[1]

Power proposed to be developed at Niagara Falls.

	Horsepower.
Niagara Falls Power Company's present tunnel	100,000
Niagara Falls Power Company's second tunnel	100,000
Niagara Falls Hydraulic Power and Manufacturing Company's canal	150,000
Canadian Niagara Power Company's tunnels	250,000
Total	600,000

The developments now in progress at Niagara Falls are being carried out on very broad lines and probably furnish the best examples of modern hydraulic work. They certainly lead so far as the

[1] For an interesting discussion as to the effect of diverting large quantities of water from Niagara River for power purposes, see report of Clemens Herschel, made December 12, 1895, on the Diversion of Water from the Niagara River for Power Purposes by the Niagara Falls Hydraulic Power and Manufacturing Company and by the Niagara Falls Power Company, and the Unimportant Effect of such Diversion upon the River. Mr. Herschel bases his discussion on the data of the Lake Survey of an ordinary and usual flow of 265,000 cubic feet per second. Reasoning from this premise he concludes that even when 300,000 or 400,000 horsepower are in use the effect upon the depth of the river will be insignificant.

United States is concerned. A complete account of both works, giving details of all the engineering features, would make a large-sized monograph. From this point of view it is only possible to cite some of the sources of information.[1]

POWER PLANT AT MASSENA, ON ST. LAWRENCE RIVER.

Among the large power developments now under construction in the State of New York is that at Massena, on St. Lawrence and Grass rivers. According to statements made by John Bogart, consulting engineer, the power plant now under construction at Massena includes the excavation of a canal leading from St. Lawrence River to Grass River, a distance of 3 miles, the building of a power house, the installation of fifteen 5,000-horsepower electric generators, and the necessary equipment of turbine water wheels. The furnishing of the electric apparatus has been awarded to the Westinghouse Electrical and Manufacturing Company, and is said to be the largest contract for electric apparatus ever placed.

The plan of development adopted at Massena is to divert a portion of the water of St. Lawrence River from its natural channel by means of a canal, carrying it 3 miles across to Grass River, where, after operating turbines, it will pass by way of Grass River to the St. Lawrence at a point lower downstream. Just below where the canal takes water from St. Lawrence River, Long Sault Rapids are located, which have a fall of about 50 feet. Grass River runs nearly parallel to the St. Lawrence for several miles, flowing into the St. Lawrence a short distance below the foot of Long Sault Rapids. To the south of St. Lawrence River, and between it and the valley of Grass River, there is a comparatively level plateau.

The average width of Grass River from its mouth to above where the power canal will intersect it is from 250 to 300 feet, and its water surface, for this portion, is substantially on a level with the St. Lawrence below the rapids; hence the surface of Grass River at the point where the power canal strikes the stream is from 45 to 50 feet below the surface of the St. Lawrence at the head of the canal. The power station will be located on the north bank of Grass River, the tail-water dropping into that stream, which thus becomes, in effect, a tailrace for this power development. Making some allowance for increased depth of water in Grass River between the power station and its mouth, when receiving the tail water, and also some allowance

[1] The main facts in regard to the plant of Niagara Falls Power Company as herein embodied have been furnished by L. H. Groat, secretary of the company. For more extended information the reader is referred to (1) Cassier's Magazine, Vol. VIII (July, 1895), where may be found an account of nearly every phase of the Niagara Falls Power Company's development; (2) The Electrical World, Vol. XXX (Oct. 23, 1897), which may be consulted for a description of the extension of the wheel pit now in process; (3) Niagara Falls publication of the Niagara Falls Chamber of Commerce, issued in 1897; (4) the various numbers for 1897 of Greater Buffalo, a monthly publication devoted to promoting the prosperity of Buffalo and Niagara Falls. Engineering News and other technical journals may also be consulted.

for inclination of the water surface of the head canal, it is thought that an absolutely permanent power of about 40 feet will be obtained.

The work of constructing the head canal and preliminary work on the foundations of the power house are now under way. It is expected that the work will be completed in 1899. The canal will be 250 feet wide and 25 feet deep, this capacity being assumed as sufficient to furnish 150,000 horsepower. The work is being carried out by the St. Lawrence Power Company, which was organized under the laws of the State of New York, with a capital stock of $6,000,000. According to statements made, a large amount of power has been taken by an English syndicate, which intends to use it chiefly for electro-chemical manufacturing.

INLAND WATERWAYS.

TRADE AND COMMERCE OF HUDSON RIVER.

The importance of Hudson River as a great waterway of commerce is shown by Mr. Charles G. Weir in a report made in 1890. Aside from its own local trade the river absorbs all the traffic of the Erie, Champlain, Delaware, and Hudson canals, besides the great coal trade of the Pennsylvania Coal Company at Newburg and the Erie coal trade at Piedmont. The average season of navigation of the river is two hundred and forty days. The two principal industries on Hudson River, which add materially to the total tonnage, are ice and brick. The capacity of the ice houses on and near the river exceeds 4,000,000 tons, and the amount annually harvested is about 3,500,000 tons. The bricks manufactured on the river exceed 850,000,000.

The following statistics include the tonnage received at all points above Spuyten Duyvil Creek, and of the local shipment between points on the river. That shipped is credited only to the points from which it was shipped, no entry being made to the total tonnage of the amount received at local points from other local points. The total tonnage also includes all through freights shipped from points up the river that passed the mouth of Spuyten Duyvil Creek going south.

Tonnage and value of commerce on Hudson River above Spuyten Duyvil Creek.

Total tonnage of all shipping points on Hudson River during 1889, not including the tonnage coming through State canals (tons)	15,033,309
Value of same	$378,196,094
Total tonnage coming to and leaving tide water through State canals, 1889 (tons)	3,592,437
Value of same	$108,000,000
Increase of same over tonnage, 1888 (tons)	326,466
Grand total tonnage of Hudson River, including tonnage through State canals (tons)	18,582,596
Value of same	$485,735,094
Number of transportation companies for passengers or freight, not including steamboats or pleasure boats	30
Total number of passengers carried, 1889	5,000,000

In regard to the foregoing statement of the capacity of ice houses on and near the river, as made by Mr. Weir, it may be remarked that Charles C. Brown, in a report on Hudson River, which appears in the Eleventh Annual Report of the State Board of Health, gives a list of ice houses on Hudson River, with their capacity in 1889. According to Mr. Brown, the total capacity in that year was 2,908,000 tons, while the crop harvested frequently exceeds this quantity by 500,000 tons, which is stacked up outside and disposed of before the warm season begins. Mr. Weir's statistics, as stated, include the capacity of ice houses on and near Hudson River, while Mr. Brown's include only those actually on the river, which probably explains the apparent discrepancy in the statistics.

STATE CANALS.

EARLY HISTORY.

The idea of a water communication between Hudson River and the West via the valley of the Mohawk had been a favored one with the statesmen of New York for many years previous to the beginning of the present century; the early projects, however, were altogether with reference to improvement of the natural water channels and did not include the construction of artificial channels further than such channels might be necessary as connecting links. Thus Sir Henry Moore, governor of the colony of New York, proposed, in December, 1768, an improvement of the navigation of the Mohawk River at Little Falls by a sluice on the plan then used on the Languedoc Canal in France.

In 1788 Elkhannah Watson proposed to establish a water communication from Hudson River and Lake Ontario by way of Oneida Lake, Oneida River, and Oswego River, his plan being to connect Wood Creek with Mohawk River by a canal and to improve the Mohawk with locks.

In January, 1791, Governor George Clinton, in an address to the legislature, urged the necessity of improving the natural water channels in order to facilitate communication with the frontier settlements. Following this address, in February of the same year, a joint committee was appointed to inquire what obstructions in the Hudson and Mohawk rivers it would be proper to remove. As the result of this inquiry, an act was passed March 24, 1791, authorizing the commissioners of the land office to explore and survey the ground from Mohawk River at Fort Stanwix (now Rome) to Wood Creek with reference to constructing an artificial channel, and also to survey Mohawk and Hudson rivers for improvement by locks and to estimate the cost of the same. A sum not exceeding $500 was appropriated to pay the expense of such survey.

At that time the channel of commerce was by the Mohawk from Albany to Fort Stanwix in boats of about 5 tons burden. Going west

these boats carried from 1½ to 2 tons and on the easterly trip 5 tons. From Fort Stanwix there was a portage of 2 miles across the flats to Wood Creek, whence the course lay into Oneida Lake and River, and from thence into Seneca and Oswego rivers to Lake Ontario; or, from points farther west, up Seneca River to Lakes Cayuga and Seneca. At that time it cost from $75 to $100 per ton for transportation from Seneca Lake to Albany. The time occupied in going from Albany to Seneca Lake was twenty-one days, and in returning eight days.

The commissioners appointed under the act of March, 1791, were Elkhannah Watson, Gen. Phillip Schuyler, and Goldsborrow Bayner. On the 3d of January, 1792, the commissioners reported the cost of improving the route from Albany to Seneca Lake by locks and canals at $200,000, whereupon the legislature passed an act March 30, 1792, incorporating the Western Inland Lock Navigation Company, for the purpose of opening navigation by locks from Hudson River to Lakes Ontario and Seneca, and the Northern Inland Lock Navigation Company, charged with performing a like service from Hudson River to Lake Champlain. The capital stock of each company consisted of 1,000 shares of $25 each, but the companies were afterwards allowed a capital stock of $300,000 and an increase of the same from time to time. George Washington, the original promoter of canals in the United States, was the first president of the Western Inland Lock Navigation Company.

In March, 1795, an act was passed directing the State treasurer to subscribe 200 shares to these companies, of $50 each. State aid was again granted by an act passed in April, 1796, by which the Western Inland Lock Navigation Company was loaned $37,500, and a mortgage taken by the State on the company's property at Little Falls. In that year a route was opened from Schenectady to Seneca Falls for boats carrying 16 tons. The locks at Little Falls were first built of wood, then of brick, and finally of stone; the remains of the latter are said still to exist. Dividends were paid for a number of years on the stock of the company making these improvements. The tariff levied for a barrel of flour carried 100 miles was 52 cents, and for a ton of goods, $5.75.

Finally New York entered upon its era of inland-water improvements under the auspices of the State itself. On April 15, 1817,[1] an act was passed entitled "An act respecting navigable communication between the great eastern and northern lakes and the Atlantic Ocean," in which it was provided that whenever in the opinion of the canal commissioners it should be for the interests of this State that all the interest and title in law and equity of the Western Inland Lock Navigation Company shall be vested in the people of this State, it should

[1] The full authority for the construction of the Erie and Champlain canals may be found in two acts, the first being chapter 237 of the laws of 1816, passed April 17, 1816; the second being chapter 262 of the laws of 1817, passed April 15, 1817. There is more or less confusion of these two dates in early canal literature.

be lawful for the canal commissioners to pass a resolution to that effect. The act then provides a procedure for taking the property of this company after the passage of such a resolution by the canal commissioners. Following this act the rights of the company were soon transferred to the State, and the property operated for two or three years thereafter under State auspices. In 1821 the State collected the sum of $450.56 for tolls charged from Rome to the lower lock at Little Falls on account of transportation over the route formerly controlled by the Western Inland Lock Navigation Company.

Chapter 144 of the laws of 1813 incorporated the Seneca Lock Navigation Company for the purpose of constructing a canal from Cayuga Lake to Seneca Lake. The rights of this company were purchased by the State, pursuant to chapter 271 of the laws of 1825. The two companies, the Western Inland Lock Navigation Company and the Seneca Lock Navigation Company, may be considered the forerunners of Erie Canal.

About $100,000 was expended by the Northern Inland Lock Navigation Company on locks around the falls at Cohoes and for their improvement, all of which proved a total loss, the rights of the company being finally transferred to the State before navigation from Hudson River to Lake Champlain was actually opened.

The amount expended by the Western Inland Lock Navigation Company up to December, 1804, was $367,743, which was increased to $480,000 in 1813, and to a total of $560,000 before the works were finally transferred to the State. The mistake of first constructing wooden locks proved a severe loss to the company, as all the original locks at Little Falls, German Flats, and Rome rotted away in about six years. The facilities afforded by these companies were undoubtedly inadequate to the demands of the rapidly growing western section, and accordingly an active agitation finally began for some more extended means of communication.

The early work was, as we have seen, entirely in the direction of the improvement of natural channels, the extent of artificial channels for the whole route from Hudson River to Seneca Lake being only 15 miles. About 1803, however, the project for an artificial canal connecting Lake Erie with tide water in the Hudson was broached by Gouverneur Morris. In 1807 Jesse Hawley wrote a series of articles on the subject, and in 1808 the legislature directed the surveyor-general, Simeon De Witt, to make a survey of such a route. This survey was made by James Geddes, who reported on January 20, 1809. In 1810 the legislature appointed commissioners to prosecute further examinations. This commission made its first report in March, 1811. After discussing the route as proposed, from Hudson River to Lake Ontario, it recommended the inland route to Lake Erie with a direct descent from Lake Erie to Hudson River. Following this report a bill was passed by the legislature reappointing the commissioners of

the previous year, with the addition of Robert R. Livingston and Robert Fulton, and extending the powers of the commissioners and adding to the appropriation for its work. The war of 1812 came on, however, and the canal project was temporarily dropped until 1816, when De Witt Clinton presented a memorial to the legislature from the city of New York urging action toward the construction of the canal. Finally the act of April 15, 1817, was passed creating a permanent board of canal commissioners,[1] which entered at once upon its duties, and providing for the construction of artificial navigation from Lake Erie to tide water on Hudson River, and also from Lake Champlain to tide water on the Hudson. The dimensions of the proposed canals were fixed by the commissioners as follows: For Erie Canal a bottom width of 28 feet, surface width 40 feet, and depth 4 feet, with locks 90 feet long and 15 feet wide; for Champlain Canal a bottom width of 20 feet, surface width 30 feet, and depth 3 feet, with locks 75 feet long and 10 feet wide.

Ground was broken for Erie Canal at Rome, July 4, 1817, and the section from Utica to Seneca River completed October 22, 1819, a boat passing from Rome to Utica on that day. Champlain Canal was opened in part for navigation November 24, 1819. The route for Erie Canal from Seneca River west was also explored in 1819, and the final location, from Seneca River to Rochester, made in 1821. The principal engineers were James Geddes, Benjamin Wright, and Canvass White.

The annual report of the canal commissioners, dated January 31, 1818, gives details of the system adopted for the construction of the canal. They state that they had decided to complete the middle section first, 58 miles of which were put under contract during the year 1817, this portion being wholly on the summit level. The whole labor performed in 1817 was equal to the completion of 15 miles. In indication of the easy character of the work, the commissioners state that three Irishmen finished 3 rods of canal in 4 feet cutting in five and one-half days, and that on the 58 miles under contract only half a mile required puddling.

The engineer's original estimate of the cost of the middle section, completed in 1819, was $1,021,851. The actual cost was $1,125,983. This increase, as stated by the commissioners, was due to change of prism and structures.

While the State canals were in progress the Seneca Lock Navigation Company, authorized by chapter 144 of the Laws of 1813, had been engaged in constructing a canal between Seneca and Cayuga lakes, including a series of locks at Seneca Falls. On June 14, 1818, a loaded boat from Schenectady, 16 tons burden, passed the newly-constructed locks at Seneca Falls. Along Mohawk River the passage

[1] The permanent board of canal commissioners of 1817 included the following men: De Witt Clinton, president; Stephen Van Rensselaer, Samuel Young, Joseph Ellicott, and Myron Holley, their appointment having been first authorized by the act of April 17, 1816.

A. ERIE CANAL AT BUFFALO, NEW YORK

B. BLACK ROCK GUARD LOCK ON ERIE CANAL

of boats of this size was effected through the locks of the Western Inland Lock Navigation Company, Erie Canal not being open for navigation at that date. The locks at Seneca Falls cost $60,000. The toll charged during 1818 was equivalent to 9 cents per ton per mile.

Champlain Canal was, as stated, opened for navigation November 24, 1819, from the Hudson at Fort Edward to Lake Champlain. The estimated cost of this section was $250,000, but on account of changing its dimensions to the same size as Erie Canal the revised estimate amounted to $333,000. The canal was finally completed from Lake Champlain to Albany on September 10, 1823.

Work on Erie Canal proceeded during the years from 1820 to 1825, in the former year 94 miles being in operation and in the latter 363. It was finally completed from Albany to Black Rock on October 26, 1825, on which day the first boat ascended the Lockport locks and passed through the mountain ridge into Lake Erie. Uninterrupted navigation was thus obtained from that lake to the Atlantic Ocean for boats of an average of about 40 tons burden. The event was made a gala day the whole length of the canal.

The construction of Erie Canal was due to the unbounded perseverance and genius of one man—Governor De Witt Clinton—who, when one studies the early history of Erie Canal, stands forth as the colossal figure of the enterprise.

The total expenditure on Erie and Champlain canals to January 1, 1826, was $9,474,373.14, from which should be deducted for pay of engineers and commissioners, the acquisition of water rights, land damages, the construction of feeders, repairs, Black Rock Harbor, lowering Onondaga outlet, Salina and Onondaga side cut, Waterford and Troy side cuts, Troy dam, and Glens Falls feeder, the sum of $1,621,274. Hence the actual cost of construction of the canal proper was $7,853,099, which, on the aggregate length of 433 miles, equals $18,136 per mile, or, taking into account the various extensions enumerated and the engineering as necessary items of expenditure, the original cost per mile of the Erie and Champlain canals may be placed at $21,881 per mile.

Between 1825 and 1833 work was begun on a number of lateral canals—as, for instance, Oswego Canal, begun in 1826 and completed in 1828; Cayuga and Seneca Canal, begun in 1827 and completed in 1829; Chemung Canal, begun in 1831 and completed in 1832, and Crooked Lake Canal, begun in 1831 and completed in 1833. The total cost of all the canals, including interest on loans up to March 23, 1833, was $11,460,066.77.

Chenango Canal was begun in 1833. The total amount expended on all the canals, including original construction, extensions, maintenance, repairs, and interest on loans, to the end of 1834 was $13,798,438, and the total amount of tolls received from 1820 to 1834, inclusive, was $10,000,730.97—that is to say, at the end of ten years

from the original completion of Erie Canal the amount returned to the State was nearly 78 per cent of the total cost to that date. This fact is of the greatest interest because it indicates that from the very beginning the New York State canal system was operated as a purely business enterprise. It is clear, then, that in reality the State of New York, in constructing its internal navigation system, went into the transportation business; by that statement it is meant that the State managed the affairs of the canals precisely as a private company would have managed them—that is, the State built its canal system and levied as heavy tolls as the articles transported would stand.

By way of illustrating how thoroughly the State was in the transportation business and on exactly the same basis as transportation companies, it may be cited that in 1830 the legislature sent a communication to the commissioners of the canal fund asking if it were not possible to increase the rate of toll on many of the articles transported, and stating that it seemed necessary, in order to meet all the interests involved, that the canals yield somewhat greater revenue. The commissioners replied to this communication at length, giving in detail the amount of toll levied on different articles transported, and finally concluded with the statement that it would be impossible to increase the tolls materially, because the articles transported were at that time taxed all they would stand. If the rate of toll were made materially greater, many articles would not be transported on the canals, but would go by other channels, as by St. Lawrence River and by the Great Lakes. The State would thus lose the benefit derived from carrying them.

About 1833 to 1835 railroads began to attract attention as means of transportation, and in 1835 John B. Jervis, Holmes Hutchinson, and Frederick C. Mills, who were the principal canal engineers of that day, were instructed to report on the relative cost of transportation on canals and railroads. In an introduction to their report by William C. Bouck and Michael Hoffman, canal commissioners, it is stated that it will not be difficult to show that the expense of transportation on railroads is materially greater than on canals. But in addition to this there were other important considerations in favor of canals:

(1) A canal may be compared to a common highway on which every man can be the carrier of his own property, therefore creating the most active competition, and thus reducing the expense of transportation to the lowest rates. The farmer, merchant, and manufacturer can avail themselves of the advantages of carrying their own product to market in a manner best comporting with the interest of each individual.

(2) Much of the property carried on the canals is carried by transportation companies, although the largest portion is carried by individuals and small associations. The individual who becomes the

carrier of his own product has the advantage of paying nearly one-half of all the expense of transportation in the regular course of his business, and the cash disbursements do not often much exceed the payment of the tolls. To the farmer the profits on return freight, in many instances, give a full indemnity for the expense of taking his cargo to market. On railroads, on the other hand, the proprietors must necessarily be the carriers.

A fixed popular belief in the two principles laid down by Messrs. Bouck and Hoffman in their introduction to the transportation report of 1835 has been the cause of a great deal of mistaken policy in the State of New York. For instance, nearly every year since the beginning of the railway era the newspapers of the State have teemed with the statement that the State must necessarily maintain the canal system in order to check the exorbitant tariff demands of competing railways. As we have seen, in 1830, just before the beginning of the railway era, the State was taxing every article transported upon the canals all that it would stand, and the system of excessive State tariffs was continued until a few years later, when the competition of the railways forced a reduction in the tariff for transportation on the canal.

GROWTH AND DECLINE OF CANAL TRANSPORTATION.

A number of reports bearing on transportation questions were submitted in 1835, and finally the fixed policy was adopted of enlarging Erie Canal, the act authorizing what is known as the Erie Canal enlargement being passed in that year. The law authorizing the enlargement directed the construction of double locks and a prism with a width at water surface of 70 feet, and a depth of 7 feet, the locks to be 110 feet long and 18 feet wide. It was estimated that an enlargement to this extent would save 50 per cent in cost of transportation, exclusive of tolls. The enlargement to this standard width and depth was begun in 1836 and continued to 1842, when the legislature directed the suspension of expenditures. In 1847 the work of enlargement was resumed, and substantially completed in 1862. Since that time to the work now in progress under the authority of chapter 79 of the laws of 1895 there has been no change in the standard of width at water line of 70 feet and depth of 7 feet. As an interesting fact it may be pointed out that while the enlargement authorized in 1835 led to vast increase in the transportation business on the State canals the cost of transportation gradually decreased, one chief cause of such decrease being the competition of railways, until in 1883 the competition from this source became too sharp to maintain longer transportation on the canals if any toll at all were charged. The canals were then made free by legislative enactment.

The popular notion, formerly prevalent in New York, that it has been necessary to maintain the State canals in order to regulate the railways, is seen to be far from true. The railways have regulated the canals quite as much or more than the canals have regulated the railways. Indeed, the railways must be considered as having the better of it, because the State has been obliged absolutely to do away with all tolls on the canals in order to insure their obtaining business at all.

In illustration of the value of the water resources afforded by the Great Lakes in conjunction with the New York State internal navigation system, the following statement of receipts of flour, wheat, corn, oats, barley, and rye at Buffalo for certain years, from 1836 to 1896, inclusive, is given.

Receipts of flour, wheat, corn, oats, barley, and rye at Buffalo from 1836 to 1896.

Year.	Flour.	Wheat.	Corn.	Oats.	Barley.	Rye.
	Barrels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1836	139,178	304,990	204,355	28,640	4,876	1,500
1840	597,142	1,004,561	71,337	-------	-------	-------
1845	746,750	1,770,740	54,200	23,300	-------	-------
1850	1,103,039	3,681,347	2,593,378	357,580	3,627	-------
1855	937,761	8,022,126	9,711,430	2,693,222	62,304	299,591
1860	1,122,335	18,502,615	386,217	1,209,594	262,158	80,822
1865	1,788,393	13,437,888	19,840,901	8,494,799	820,563	877,676
1870	1,470,391	20,556,722	9,410,128	6,846,983	1,821,154	626,154
1875	1,810,402	32,987,656	22,593,891	8,494,124	916,889	222,126
1880	1,317,911	40,510,229	62,214,417	649,351	335,925	743,451
1885	2,993,280	27,130,400	21,028,230	767,580	577,230	309,370
1890	6,245,580	14,868,630	44,136,660	13,860,780	5,165,700	1,281,030
1895	8,971,740	46,848,510	38,244,960	21,943,680	10,253,440	787,340
1896	10,384,184	54,411,207	47,811,010	40,107,499	16,697,744	4,404,354

A comparison of the statistics of railroad and canal traffic shows at once the vast preponderance of freight carried by the several railways centering at New York in comparison with that carried by Erie Canal. In spite of the fact that the canal was made free in 1883, figures indicate that since that time there has been a continual decrease in the amount of freight carried on the canals. Probably no feature of this change is more significant than that of the internal movement in New York State. In 1889 the total movement within the State was 1,438,759 tons, while in 1896 it was only 565,482 tons. These statistics show at once the decreasing estimation in which Erie Canal as a means of transportation is held by the great body of shippers in the State of New York. One of the results of this decrease is graphically

EFFECT OF DECREASE OF BUSINESS ON ERIE CANAL.

depicted in Pl. X, showing the fleet of boats tied up and awaiting business.

By way of illustrating the growth and decline of the business of the New York State canals from about 1835–36 to the present time the following statement of total tonnage of all freight on the canals, ascending and descending, and the value of the same for certain years from 1837 to 1896, inclusive, is presented:

Tonnage of freight on New York State canals and value of same, 1837 to 1896.

Year.	Tons.	Value.
1837	1,171,296	$55,809,288
1840	1,416,046	66,303,892
1845	1,977,565	100,629,859
1850	3,076,617	156,397,929
1855	4,022,617	204,390,147
1860	4,650,214	170,849,198
1865	4,729,654	256,237,104
1870	6,173,769	231,836,176
1875	4,859,958	145,008,575
1880	6,457,656	247,844,790
1885	4,731,784	119,536,189
1890	5,246,102	145,761,086
1895	3,500,314	97,453,021
1896	3,714,894	100,039,578

Without analyzing the figures in detail, it is sufficient to point out that if it is true, as popularly supposed, that Erie Canal ought to be maintained as a medium of competition with the railways, the figures derived from the annual statements of the chief competitor of Erie Canal must be taken as conclusive that the competition has, on the whole, been a failure. The railway, developed as a private enterprise, has not only been able to carry freight as cheaply as the canal, but has been able to charge for the same and do the work at a profit. In the year ending June 30, 1897, the New York Central and Hudson River Railway Company paid a dividend on its stock of $4,000,000, besides carrying $51,866.80 to the surplus account, whereas the canal, although all tolls were removed in 1883, has still been unable to compete. Among the chief reasons for this result we may mention lack of organization of the canal system. The perpetuation of the idea that one advantage of the canals was that they were common highways on which each man could carry his own products to market has tended largely to produce this unsatisfactory result. Thus far there has never been any systematic organization for obtaining business for the canal. The boats are owned by small proprietors, each operating from one to three or four boats. When cargoes in hand are discharged

at either terminus, each owner solicits another cargo. The results are delays, half cargoes, and consequent loss. During the last few years it has been only by the most rigid economy that Erie Canal boatmen could live. On the other hand, the business of soliciting freight for the railways is compactly organized and every possible advantage taken of the situation.

However unsatisfactory it may seem to the individual boatman, the future of effective transportation on Erie Canal depends, in the opinion of the author, on the organization of large transportation companies which conduct the business of carrying freight by canal on the same business basis as adopted by railways. As to the equity of the State furnishing and maintaining a waterway on which transportation may be conducted by such corporations at a profit the author expresses no opinion further than to point out that the official discussion of such a proposition by the State engineer and surveyor in his annual report for the year ending September 30, 1896, may be taken to indicate that the day of Erie Canal as a State waterway has passed.

COST AND REVENUES OF THE NEW YORK STATE CANAL SYSTEM.

The accompanying table exhibits the total cost of construction, maintenance and operation, and the total revenues from all sources of the several canals of New York from their original inception to September 30, 1892.

Cost of construction, maintenance and operation, and revenues of New York canal system.

Canals.	Cost of construction.	Cost of maintenance and operation.	Total cost.	Revenue from all sources.	Loss.	Gain.
Erie and Champlain	$57,688,676	$41,582,759	$99,271,435	$128,191,068	----------	$28,919,633
Oswego	4,643,921	3,736,676	8,380,597	3,715,567	$4,665,030	----------
Cayuga and Seneca	1,886,662	1,157,754	3,044,416	1,055,016	1,989,400	----------
Black River	4,077,882	2,082,251	6,160,133	305,663	5,854,470	----------
Oneida River improvement	233,962	41,236	275,198	214,428	60,770	----------
Oneida Lake	513,439	144,060	657,499	65,180	592,319	----------
Baldwinsville (so called)	31,000	18,039	49,039	1,261	47,778	----------
Seneca River towing path	1,602	20	1,622	7,782	----------	6,160
Cayuga Inlet	2,020	948	2,968	7,534	----------	4,566
Crooked Lake (abandoned)	395,092	424,658	819,750	45,490	774,260	----------
Chenango (abandoned)	4,807,952	2,105,217	6,913,169	744,027	6,169,142	----------
Chemung (abandoned)	1,512,041	2,022,259	3,534,300	525,565	3,008,735	----------
Genesee Valley (abandoned)	6,741,839	2,814,809	9,556,648	860,165	8,696,483	----------
Total	82,536,088	56,130,686	138,666,774	135,738,746	31,858,387	28,930,359

The total cost of Crooked Lake, Chenango, Chemung, and Genesee Valley canals, which were abandoned under the provisions of the law of 1877, was $20,823,867, and the total revenue from all sources $2,175,247. The total loss on the abandoned canals was, therefore, $18,648,620. The following is the complete financial exhibit of all canals from their inception to September 30, 1892: Total loss on abandoned canals, $18,648,620; net gain on canals now in operation, $15,720,592; loss on the whole system, $2,928,028.

IMPROVEMENT OF ERIE CANAL.

The canal improvement now in progress was formulated by State Engineer and Surveyor Horatio Seymour, jr., about 1878 or 1879. In his annual report for the fiscal year ending September 30, 1878, Mr. Seymour discusses extensively transportation questions as related to Erie Canal, pointing out that transportation can be cheapened in two ways—by increasing the tonnage of boats or by increasing their speed. As to increasing the tonnage of boats, he states that two methods may be used—the locks may be lengthened or the depth of water may be increased. He refers to experiments made by Elnathan Sweet by which it was shown that the best form of waterway should have a cross section 5.39 times the immerged section of the boat, and a surface width 4.5 times the width of the boat. The width of the canal, Mr. Seymour states, is substantially what it should be, but it lacks the necessary depth in order to conform to the law of relation of cross section of water to immerged section of boat, as determined by Mr. Sweet. Reports are submitted showing that an additional depth of 1 foot could be obtained for about $1,100,000.

The matter of making the improvement, however, remained in abeyance until the passage of an act in 1895, which provided for submitting to the people at the State election in November of that year the question as to whether an improvement by deepening 2 feet should be undertaken, at an expense of $9,000,000. Section 3 of chapter 79 of the laws of 1895 reads as follows:

> Within three months after issuing of the said bonds the superintendent of public works is hereby directed to proceed to enlarge and improve the Erie Canal, the Champlain Canal, and the Oswego Canal; the said improvement to the Erie and Oswego canals shall consist of deepening the same to a depth of not less than 9 feet of water, except over and across aqueducts, miter sills, culverts, and other permanent structures, where the depth of water shall be at least 8 feet, but the deepening may be performed by raising the banks wherever the same may be practicable; also the lengthening or improving of the locks which now remain to be lengthened, and providing the necessary machinery for drawing boats into the improved locks, and for building vertical stone walls, where, in the opinion of the State engineer and surveyor and superintendent of public works, it may be necessary. The improvement upon the Champlain Canal shall consist in deepening the said canal to 7 feet of water, and the building of such vertical stone walls

as, in the opinion of the State engineer and surveyor and superintendent of public works, may be necessary.

The necessary preliminary work was so far completed that bids for constructing the improvement were called for in October, 1896, and shortly thereafter contracts for work amounting to about $4,000,000 were awarded. The canal was closed December 1, 1896, and soon after work was begun and continued until May 5, 1897, when navigation was opened for the season of 1897, and all contractors not working with dredges discontinued operations until the winter of 1897–98. The act authorizing the present improvement provided, as we have seen, that the deepening of the canal prism might be accomplished either by excavation or by raising the side walls. As a matter of fact, sometimes one method and sometimes the other has been followed, depending upon the conditions of each level. Usually, however, a part of the increased depth has been obtained by raising the side walls, with the balance secured by excavation.

As is indicated in the extract from the act authorizing the present improvement, the work includes the lengthening of such locks as have not been previously lengthened. The original locks of the enlargement of 1836 to 1862 were 110 feet long by 18 feet wide. In 1885 work was begun lengthening these locks to 220 feet, or about 210 feet in the clear, thus permitting two boats to pass through at one lockage. Up to the present time 42 of the 72 original locks have been lengthened. The 30 locks yet remaining to be dealt with are mostly bunched in groups or flights, as, for instance, at Cohoes, where 16 locks effect a change of level of 140 feet, and at Lockport, where 5 locks effect a change of 58 feet. In order to lengthen locks built in flights it would be necessary to entirely reconstruct them, and as the restricted space, especially at Lockport, would render this a very difficult thing to do in one winter season, it has therefore been proposed to construct at Cohoes and Lockport, and possibly at Newark, vertical lift locks to take the place of the ordinary locks now in use at these places. The State engineer and surveyor has completed the plans for the proposed lift lock at Lockport, which is so located as not to interfere with the use of the locks now in place there during its construction. It has been announced that the $9,000,000 appropriated will fall about $7,000,000 short of completing the work of deepening and lengthening on the lines thus far carried out, and in consequence the matter of building the lift locks is held in abeyance.[1]

[1] For engineering and other details of the canal improvement now in progress see Eng. News, Vol. XXXVIII (Sept. 2, 16, and 23, 1897). See also Effect of depth upon artificial waterways, by Thomas C. Clark: Trans. Am. Soc. Civil Eng., Vol. XXXV, pp. 1–40. Also Eng. News, January 6, 1898, for discussion of the question, What shall New York do with its canals?

DESCRIPTION OF THE CANALS NOW IN OPERATION, AND THEIR WATER SUPPLY.

Following are some of the main facts in regard to the principal canals—Erie, Champlain, Oswego, and Black River—now in operation in the State of New York. Similar facts for Oneida Lake Canal, Oneida River improvement, the Cayuga and Seneca Canal, and others, may be obtained by reference to the annual reports of the superintendent of public works.

Length, capacity, and cost of New York State canals.

ERIE CANAL.

	Original canal.	Enlargement.
Length, in miles	363.00	351.78
Lockage, in feet	675.50	645.80
Average burden of boats, in tons	70.00	210.00
Maximum burden of boats, in tons	76.00	240.00
Construction authorized	Apr. 15, 1817	May 11, 1835
Construction completed	Oct., 1836	Sept., 1862
Actual cost of construction	$7,143,789	$44,465,414

CHAMPLAIN CANAL.

Length of canal, in miles	66
Length of feeder, in miles	7
Length of pond, in miles	5
Total, in miles	78
Construction authorized	Apr. 15, 1817
Glens Falls feeder authorized	Apr., 1822
Estimated cost of canal	$871,000
Total cost of canal and feeder to 1868	2,378,910
Total cost, including improvements and enlargements, to 1875	4,044,000

OSWEGO CANAL.

	Original canal.	Enlarged canal.
Length, in miles	38.00	38.00
Lockage, in feet	154.85	154.85
Average burden of boats, in tons	62.00	225.00
Construction authorized	Apr., 1825	Apr., 1854
Construction completed	Dec., 1828	Sept., 1862
Actual cost of construction	$565,473	$4,427,589

Length, capacity, and cost of New York State canals—Continued.

BLACK RIVER CANAL.

Length of canal, Rome to Lyons Falls, in miles	35.00
Length of improved river to Carthage, in miles	42.00
Length of navigable feeder, in miles	10.50
Lockage, in feet	1,082.25
Average burden of boats, in tons	48.00
Construction authorized	Apr., 1836
Construction completed	1849
Actual cost of construction	$3,581,954

EASTERN DIVISION OF ERIE CANAL.

Erie Canal is divided into three divisions, known as the eastern, the middle, and the western. The eastern division embraces the portion of the canal, with its feeders and side cuts, extending from the Hudson River at Albany to the dividing line between the counties of Herkimer and Oneida, and the whole of the Champlain Canal, with its feeders, ponds, and side cuts. The entire mileage of canals, feeders, and river improvements on the eastern division is as follows:

Mileage of eastern division of Erie Canal.

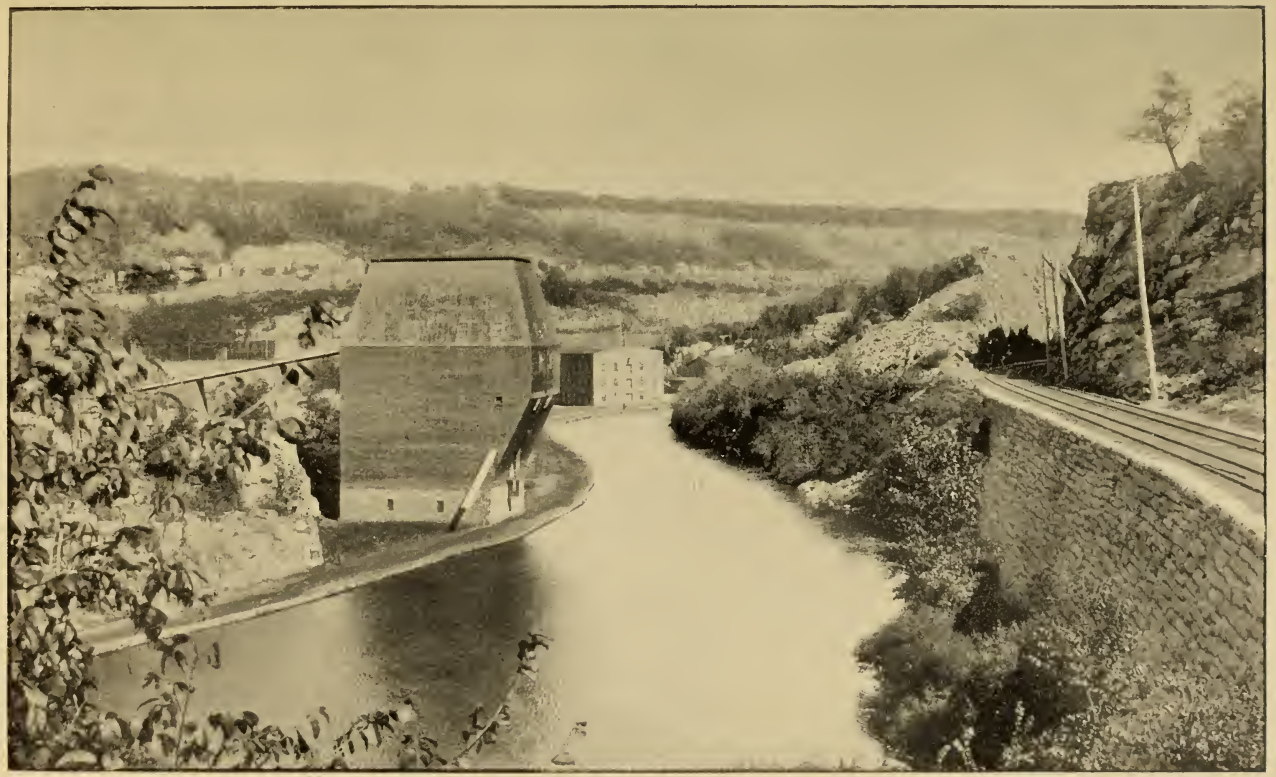
	Miles.
Erie Canal, Albany to east line of Oneida County	106.24
Fort Schuyler and West Troy side cuts	0.35
Albany basin	0.77
Champlain Canal, including Waterford side cut	66.00
Navigable river above Troy dam	3.00
Glens Falls feeder	7.00
Navigable river above Glens Falls feeder dam	5.00
Total	188.36

Mileage of unnavigable feeders of the eastern division of Erie Canal.

	Miles.
Mohawk River at Rexford Flats	0.39
Mohawk River at Rocky Rift	3.92
Mohawk River at Little Falls	0.19
Schoharie Creek	0.63
Total	5.13

WATER SUPPLY OF THE EASTERN DIVISION.

To the west of Little Falls, on the Erie Canal, lies 19.2 miles of the eastern division, supplied from the reservoirs and streams of the middle division. East of Little Falls the supply is from Mohawk River, through Little Falls, Rocky Rift, and Rexford Flats feeders, and from Schoharie Creek through Schoharie Creek feeder. As to the quantity of water used on that portion of Erie Canal included in the eastern division very little is known. With the exception of a few thousand cubic feet per minute received from the middle division, the supply is, as just indicated, all derived from Mohawk River and



ERIE CANAL AT LITTLE FALLS, NEW YORK.

its tributary, Schoharie Creek. Thus far no measurements of the actual quantity used have been made. Probably the total diversion amounts in dry weather to from 500 to 600 cubic feet per second. Some of this is returned to Mohawk River by leakage and wastage, but just what proportion is returned, and what finally delivered either into Hudson River at Albany or by the Troy and Fort Schuyler side cuts, is not known. In view of the magnitude of the power development on Mohawk River at Cohoes it appears very desirable that such a determination be made.

The water supply of Champlain Canal is derived from Wood Creek and several small streams to the north of Fort Edward, Glens Falls feeder, Hudson River feeder, from Hudson River itself at Saratoga dam, and from Mohawk River at the Cohoes dam. An investigation of the amount of water diverted from Hudson River for the supply of Champlain Canal was made by the author in the fall of 1895.

As already stated, Champlain Canal is fed from Hudson River by Glens Falls feeder, which connects with the river about 2 miles above Glens Falls and from the Saratoga dam at Northumberland.

The length of Glens Falls feeder, from the guard lock at its head to where it enters Champlain Canal, about 2 miles above Fort Edward, is 6.92 miles. From this point the water in the canal flows both north and south, the total length of canal fed by Glens Falls feeder being 31.81 miles. Fort Edward level, into which Glens Falls feeder delivers water, is a summit level, and hence the water delivered into it, less the losses by percolation, evaporation, etc., is partly discharged into Lake Champlain and partly into Hudson River at Saratoga dam. Champlain Canal crosses through the pond formed by Saratoga dam from the east side to the west of the Hudson and again passes out of the river, taking a full supply therefrom at the village of Northumberland, from which point to Mohawk River at Cohoes the distance is 27.06 miles. The water from this section by passing into the Mohawk finally reaches the Hudson above the Troy dam. The canal crosses Mohawk River at Cohoes, taking water therefrom to supply the section from Cohoes to near West Troy, a distance of 2.36 miles. A small amount of water also passes from Champlain Canal to the Hudson through the Waterford side cut.

Since the construction of Glens Falls feeder there have existed serious leaks though the seamy limestone rock in which the feeder is excavated at and below the village of Glens Falls. It is claimed that the losses through these seams have generally increased, until for several years past they have amounted to about 50 per cent of the total flow into the feeder at the guard lock.

This leakage has been repeatedly complained of by the owners of water power at Glens Falls and several attempts to check it have been made, but without much avail. The river falls 38 feet at Glens Falls, and the owners of the water power there claim that this leakage,

which is practically all below the falls, is a detriment to their water power which ought not to exist. In order to determine the amount of this leakage, as well as the relation which it bears to the question of a material increase in the flow of Hudson River by storage, a series of measurements of the flow of the feeder was undertaken early in October, 1895.

Arrangements having been made with the division superintendent to maintain a uniform feed for several days before the measurements began, as well as during the days when they were actually being made, and points established for verifying the uniformity of the flow during the time of the measurements, a series of accurate sections was then made at points both above and below the leakage, and a large number of current-meter readings taken from a footbridge thrown temporarily across the feeder at each section. The results so obtained are as follows:

(1) On October 8, 1895, the flow in the feeder just below the guard lock at the feeder dam, above all serious leaks, was 383 cubic feet per second.

(2) On the same day the flow at change bridge No. 13, about one-half mile from the feeder dam, above all serious leaks, was 364 cubic feet per second.

(3) On October 9 and 10 the flow a short distance below all serious leaks was 213 cubic feet per second.

(4) On October 10 the flow about half a mile farther down was 191 cubic feet per second.

(5) On October 11 the flow just above the locks at Sandy Hill was 182 cubic feet per second.

(6) A section, also taken October 11, in Champlain Canal, a short distance north of where the feeder enters, shows that the amount of water passing to the north at that time was 74 cubic feet per second.

These measurements show that the loss between sections 1 and 5, which may be taken as including about all the losses from the feeder, is 201 cubic feet per second. The water delivered into Champlain Canal is, therefore, only about 47 per cent of the quantity entering the feeder at the guard lock. The measurements also show that of the 182 cubic feet per second actually delivered to Champlain Canal 74 cubic feet per second is diverted to the north, and 108 cubic feet per second, less the loss from evaporation, etc., is returned to the river at the Saratoga dam.

Since the foregoing measurements were made, the enlargement of Champlain Canal has been begun, and its effect, by tearing up the old bottom, will undoubtedly be to decrease considerably the supply of water for the next few years. Taking into account this decrease, as well as the larger losses from evaporation and absorption by vegetation during the summer months, we may place the demands for the

enlarged Champlain Canal during the months of canal navigation at the following approximate monthly means:

Water required for the enlarged Champlain Canal.

	Second-feet.
May	553
June	600
July	600
August	600
September	553
October	510
November	495

With the leakage of Glens Falls feeder done away with, the foregoing figures may be reduced about 200 cubic feet per second for each month. For the section of Champlain Canal from Northumberland to Cohoes we may assume the water supply of the enlarged canal at about 255 cubic feet per second in May, October, and November, and at about 280 to 290 cubic feet per second in June, July, August, and September.

MIDDLE DIVISION.

This division comprises that portion of Erie Canal lying between the east line of Oneida County and the east line of Wayne County, as well as Oswego Canal from Syracuse to Oswego, the Baldwinsville side cut, the Cayuga and Seneca Canal, Black River Canal, and other short stretches as indicated in detail below. The following are the lengths in miles of the several sections:

Mileage of the middle division of Erie Canal.

	Miles.
Erie Canal from east line of Oneida County to east line of Wayne County	97.02
Oswego Canal	37.78
Side cuts and slips at Salina	2.02
Slips at Liverpool	.25
Baldwinsville side cut	.59
Cayuga and Seneca Canal	22.99
Black River Canal	35.52
Old Oneida Lake Canal	1.05
Chenango slip	.05
Chemung Canal, original lake level	2.53
Total	199.80

Mileage of river improvements pertaining to the middle division of Erie Canal.

	Miles.
Black River	42.50
Onondaga outlet	.75
Oneida River	20
Seneca River towing path	5.83
Seneca River	Not used.
Ithaca inlet	2.05
Seneca outlet	.17
Total	71.30

Mileage of navigable feeders of the middle division of Erie Canal.

	Miles.
Limestone Creek feeder	0.83
Butternut Creek feeder	1.67
Camillus feeder	1.04
Delta feeder	1.40
Black River feeder	11.29
Total	16.23

The total length of canal, river improvement, and navigable feeders on the middle division is thus found to be 299.08 miles. The following feeders of the middle division are not navigable:

Mileage of unnavigable feeders of the middle division of Erie Canal.

	Miles.
Chenango Canal, summit level	5.31
Leland Pond feeder	.31
Madison Brook feeder	2.99
West Branch feeder	5.83
Bradleys Brook feeder	.67
Hatch Lake feeder	.23
Kings Brook feeder	1.87
Oriskany Creek feeder	.53
Mohawk feeder at Rome	.03
Oneida Creek feeder	2.91
Cowasselon Creek feeder	.40
Chittenango Creek feeder	.28
Cazenovia Lake outlet	.51
Tioughnioga River feeder	1.00
De Ruyter reservoir outlet	.12
Orville reeder	.55
Camillus feeder (unnavigable portion)	.65
Carpenter Brook feeder	.18
Skaneateles Creek feeder	.09
Putnam Brook feeder	.20
Centerport feeder	.18
Owasco Creek feeder	2.10
Lansing Kill feeder	1.80
Sugar River feeder	.14
Canachagala Lake outlet	.16
Total	29.04

Rome level, which is a summit level, extends from lock No. 46 to lock No. 47, a distance of 55.96 miles. The following is the estimated water supply of this level before the beginning of the enlargement now in progress.

ERIE CANAL AT SYRACUSE, NEW YORK.

Water supply of Rome level, Erie Canal.

	Second-feet.
Lelands Pond, Madison Brook reservoir, Eaton Brook reservoir, Bradley Brook reservoir, Hatch Lake, Kingsley Brook reservoir, and Oriskany Creek feed through the Chenango Canal, Oriskany Creek, and Oriskany Creek feeder into the Rome level, 6 miles west of lock No. 46	100
Mohawk River, Black River, Forestport Pond, Forestport reservoir, White Lake reservoir, Chub Lake, Sand Lake, First, Second, and Third Bisby lakes, Woodhull reservoir, Twin Lakes, South Branch reservoir, North Branch reservoir, and Canachagala Lake feed through the Rome feeder and Black River Canal into the Rome level at Rome, 14 miles west of lock No. 46	217
Oneida Creek enters canal through feeder 30 miles west of lock No. 46	17
Cowasselon Creek enters canal through feeder 31.5 miles west of lock No. 46	3
Cazenovia Lake reservoir, Erieville reservoir, and Chittenango Creek enter canal through Chittenango Creek feeder, 41.5 miles west of lock No. 46; average for navigation season about	47
De Ruyter reservoir enters canal through Limestone Creek (Fayetteville) feeder, 50 miles west of lock No. 46; average for the navigation season about	32
Limestone Creek (natural flow) also enters canal through Limestone Creek (Fayetteville) feeder, 50 miles west of lock No. 46	8
Jamesville reservoir enters canal through Orville feeder, 52 miles west of look No. 46; average for navigation season	11
Butternut Creek (natural flow) enters canal through Orville feeder, 52 miles west of lock No. 46	8
Total	443

Jordan level, which is also a summit level, extends from lock No. 50 to lock No. 51 and is 14.903 miles in length. The following feeders are tributary to this level:

Water supply of Jordan level, Erie Canal.

	Second-feet.
Otisco Lake reservoir fed through Camillus feeder into the canal, 4 miles west of lock No. 50	86
Ninemile Creek (natural flow) also fed into canal through Camillus feeder	13
Carpenter Brook feeder	3
Skaneateles feeder	146
Total	248

The following feeders deliver water into the Port Byron level, which extends from lock No. 51 to No. 52, a distance of 7.79 miles:

Water supply of Port Byron level, Erie Canal.

	Second-feet.
Putnam Brook feeder at Weedsport	3
Owasco feeder	69
Total	72

Oswego Canal receives about 167 cubic feet per second from Erie Canal at Syracuse. The balance of its water supply is derived from Seneca and Oneida rivers. The total amounts to about 1,400 cubic feet per second. Seneca and Cayuga Canal receives about 67 cubic feet per second from Erie Canal at Montezuma, and 300 cubic feet

per second from Seneca Lake, making a total of 367 cubic feet per second.

The approximate water supply of the middle division of Erie Canal at present may therefore be summarized as follows:

Water supply of the middle division of Erie Canal.

	Second-feet.
Frankfort and Rome level	443
Jordan level	249
Port Byron level	70
Total	762
Oswego Canal:	
Supply from Seneca River	900
From Oneida River	333
Total	1,233
Seneca and Cayuga Canal	300
Grand total	2,295

The present total water supply of middle division may thus be placed, approximately, at 2,295 second-feet.[1]

RESERVOIRS OF THE MIDDLE DIVISION.

As indicated in the preceding statement of the water supply of the middle division, this division has an extensive system of reservoirs, as, for instance, Owasco Lake, the original surface of which has been raised by a dam on the outlet about half a mile below the foot of the lake. Skaneateles and Otisco lakes have also been raised by similar constructions. Proceeding east, the next reservoir is the Jamesville, formed by a dam on Butternut Creek. De Ruyter reservoir is on the dividing ridge, at the extreme head waters of Limestone Creek, and supplied by a feeder from the head waters of Tioughnioga River, a tributary of Chenango River. On Chittenango Creek, the next stream east of Limestone Creek, we find Cazenovia Lake, controlled by a dam at its foot and Erieville reservoir on the extreme head waters.

On the head waters of Oriskany Creek and Chenango River there is an extensive reservoir system, originally constructed for the purpose of supplying the summit level of Chenango Canal, but which has been retained in use for the water supply of the middle division, the water therefrom being conducted to Erie Canal at Utica, through the old prism of Chenango Canal, retained as a feeder, or to Erie Canal at Oriskany, through the natural channel of Oriskany Creek and a short feeder at Oriskany village. The reservoirs on the head waters of Oriskany Creek are Madison Brook and Lelands Pond reservoirs; those on the head waters of Chenango Creek, and which are connected with the summit level of the old Chenango Canal by a feeder

[1] This is a very general statement, and to be taken in connection with a large amount of detailed information in the reports not specifically cited at this time.

several miles in length, are Eaton Brook, Hatch Lake, Bradley Brook, and Kingsley Brook reservoirs.

Reference may also be made to the reservoirs on Black River and its tributaries. These are: Woodhull, Bisby Lakes Nos. 1, 2, and 3, Sand Lake, Chub Lake, White Lake, Canachagala Lake, North Branch Lake, South Branch Lake, Twin Lakes, and Forestport and Stillwater reservoirs. The Bisby Lakes have been abandoned. The details of these reservoirs on Black River, as well as those of all other reservoirs thus far connected for the water supply of Erie Canal, may be obtained from the table on page 166.

WESTERN DIVISION.

The western division of Erie Canal includes the following:

Mileage of the western division of Erie Canal.

	Miles.
Erie Canal from the east line of Wayne County to Hamburg street, in the city of Buffalo	148.92
Five slips in the city of Buffalo, aggregate length	1.60
Genesee River feeder in the city of Rochester	2.25
Total	152.77

The unnavigable feeders of this division are:

Mileage of the unnavigable feeders of the western division, Erie Canal.

	Miles.
Tonawanda and Oak Orchard Creek	11.55
Prism of old Genesee Valley Canal, Cuba reservoir to Rockville	7.65
Prism of old Genesee Valley Canal, Scottsville to Rochester feeder dam	11.00
Total	30.20

The only reservoirs on the western division are the Oil Creek and Rockville reservoirs, originally constructed to feed the summit level of Genesee Valley Canal, and still retained as subsidiary feeders to Erie Canal, their waters being finally discharged into Genesee River and thence taken into the canal through Genesee River at Rochester. The main characteristics of Oil Creek and Rockville reservoirs may be obtained from the table on page 166.

The sources of water supply for the western division are: Lake Erie, at Buffalo; Tonawanda Creek, at Pendleton; Tonawanda and Oak Orchard creeks, at Medina; Allens Creek, through the prism of the old Genesee Valley Canal, from Scottsville to Rochester; the Genesee River at Rochester.[1]

[1] The foregoing statements as to length, water supply, and reservoirs of Erie Canal, while covering only a small amount of the total data, are still as much as can be given at this time. Full information may be obtained by reference either to the annual reports of the State engineer and surveyor from 1850 to 1896, inclusive, or of the superintendent of public works from 1878 to 1896, inclusive. Previous to 1878 the reports of the canal commissioners may also be consulted for a large amount of useful information.

Reservoirs for the water supply of Erie Canal.

Reservoir.	Date of completion.	Elevation.	Distance to canal.	Flow-line area.	Height of flow line.	Average area.	Average depth.	Capacity.	Original cost.	Cost per million cubic feet.
		Feet.	*Miles.*	*Acres.*	*Ft.*	*Acres.*	*Feet.*	*Cubic feet.*		
ROME LEVEL—ERIE CANAL		428								
Woodhull	1859	1,854	25.0	1,236	16	1,118	18.0	876,550,000	$24,089	$27.47
Bisby Lake, No. 1 *a*	1881	2,018	27.8	156	4					
Bisby Lake, No. 2	1881	2,018	27.0	204	4		3.5	40,000,000		
Bisby Lake, No. 3	1881	2,006	26.0	41	4					
Sand Lake	1872	1,808	24.0	344	18	306	15.0	199,879,822	5,505	27.71
Chubb Lake	1881	1,599	20.5	530	22	200	4.0	34,848,000	8,134	233.43
White Lake	1881		18.0	332	5	296	5.0	64,468,800	5,102	79.27
Canachagala Lake	1881		32.0	347	4	320	4.0	55,756,800	1,456	26.11
North Branch Lake	1857	1,821	25.5	423	28	277	28.0	337,851,360	34,637	102.22
South Branch Lake	1859	2,019	26.0	518	26	372	26.0	421,312,320	20,168	47.87
Twin Lakes	1881		22.9	212	6	175	8.0	60,984,000		
Forestport Pond	1853	1,124	10.5	160			2.0	13,921,920		
Forestport reservoir	1894	1,139	12.5	793	21	700	7.0	212,444,000		
BOONVILLE LEVEL—BLACK RIVER CANAL		1,121	25.0							
JORDAN LEVEL—ERIE CANAL		408								
Skaneateles Lake	1844	864	9.0	8,320			9.0	2,174,512,000	14,928	6.87
Otisco Lake	1869		12.0	2,200			10.0	784,000,000	43,753	55.81
PORT BYRON LEVEL—ERIE CANAL		403								
Owasco Lake	1866	704	12.0	680			5.0	1,481,040,000	36,296	25.59
ROCHESTER LEVEL—ERIE CANAL		508								
CUBA LEVEL—GENESEE VALLEY CANAL		1,489								
Oil Creek	1858		91.0	605	65	525	15.0	435,738,000	69,216	158.85
Rockville	1842		8.30			72	20.0	18,200,000	7,711	423.68
ROME LEVEL—ERIE CANAL		428								
Erieville	1850	1,577	20.0	340	46		21.5	318,424,000	36,837	115.68
Cazenovia Lake	1857	1,176	10.0	1,778			4.5	348,523,000	10,885	31.23
De Ruyter	1863	1,276	25.0	626			18.5	504,468,000	78,761	156.13
Jamesville	1874	585	6.0	252		240	16.0	170,000,000	150,000	882.35
Hatch Lake *b*	1836		36.0	134	15		10.0	58,370,400	4,464	76.47
Eaton Brook *b*	1836		38.0	254	60	244	50.0	553,212,000	28,059	50.72
Bradley Brook *b*	1836		35.0	134	30		25.0	145,926,000	16,159	110.73
Leland Pond *b*	1836		25.0	173	13	150	8.0	59,287,040	8,894	150.02
Madison Brook	1836	1,127	29.0	345	55	235	45.0	460,647,000	36,301	78.80
Kingsley Brook	1867		33.0	113			20.0	98,445,600	80,481	817.54

a Supply to canal through Forestport Pond and Black River Canal.
b Supply to canal through Oriskany Creek feeder.

SHIP-CANAL PROJECTS AND WATER SUPPLY.

By virtue of the geographic position of New York, with the Great Lakes on its western boundary and the Atlantic Ocean on its eastern, and with the commercial capital of the Western Continent as its chief city, all discussions of deep waterway projects from the Upper

Great Lakes to the seaboard are, necessarily, chiefly discussions of the water resources of New York. It is proper, therefore, that the several deep water projects now under discussion should be briefly noticed in a report of this character.

In February, 1895, Congress by a joint resolution authorized a preliminary inquiry concerning deep waterways between the Great Lakes and the ocean, and provided that the President should appoint three commissioners to make such inquiry. The President, under this resolution, appointed Prof. James B. Angell, of Ann Harbor, Michigan; John E. Russell, of Leicester, Massachusetts, and Lyman E. Cooley, of Chicago, Illinois. The report of the commission, as published in 1897, includes a large amount of valuable information in regard to a deep waterway from the Upper Great Lakes to the Atlantic seaboard. In regard to the State of New York, it has been pointed out by Mr. Cooley that nature has indicated two feasible routes for such a canal. The first of these is the Oswego-Mohawk-Hudson route, extending from Oswego through the valley of Oswego and Oneida rivers, and thence across the divide to the Mohawk, thence through Mohawk Valley to a point on the Hudson in the vicinity of Troy, and so on through Hudson River to tide water at New York. One objection to this route is the lockage over the summit between Lake Ontario and Mohawk Valley. Another objection is the absorption of a large quantity of water in central New York for the supply of the summit level of the canal, and which probably can be more effectively used in manufacturing; that is to say, the State of New York, by developing its manufacturing resources to their fullest extent, can realize more return from manufacturing than from the use of its inland waters for purposes of internal navigation of any kind whatever. It may be pointed out in passing that the Oswego-Mohawk-Hudson route would utilize the great natural highway which has been an easy passage to commerce from the early days of settlement on the Atlantic coast.

The second natural route through the State of New York is by way of St. Lawrence River to the head of Coteau Rapids, where the low-water level of Lake St. Francis is 153.5 feet above tide, or 68.5 feet above the low-water level of Lake Champlain. On this plan a canal would be constructed from Coteau Landing to the head of Lake Champlain, near Rouses Point, this section requiring cutting through a summit about 50 feet in height. Lake Champlain would then be utilized to Whitehall, from which point a canal would be cut through the valley leading from Whitehall to Hudson River at Fort Edward, the elevation of the water surface of the Hudson a few miles below Fort Edward being somewhat less than the low-water elevation of Lake Champlain. After reaching the Hudson the work would include the deepening of that stream to deep water, a few miles below Albany. Either of the foregoing projects would further include the construction of a ship canal connecting Lakes Erie and Ontario.

The advantage of the St. Lawrence-Champlain-Hudson over the Oswego-Mohawk-Hudson route is that the lockage would be all in one direction; that is, eastward-bound vessels would lock down all the way from Lake Erie to New York. Its disadvantages are increased length and the location of the canal connecting St. Lawrence River with Lake Champlain in Canadian territory. In regard to increased length, it is claimed that not much more time would be required in traversing it than would be consumed in locking over the Oswego-Mohawk summit.

As to the capacity of the proposed canal, the Deep Waterways Commission points out in its report that such a canal, if built, should be so carried out as to be adequate for vessels of the most economical type, not only for coasting or domestic trade but also for the foreign movement, so that commerce may be carried on directly between lake ports and other domestic and foreign ports without transshipment. Taking into account various other conditions, the commission believes that the requirements of the present demand a limiting draft in the proposed canal of 27 or 28 feet; hence, in concluding the general discussion, the commission recommends the securing of a channel of a navigable depth of not less than 28 feet.

The commission also says that, starting from the heads of Lakes Michigan and Superior, the most eligible route for a deep waterway is through the several Great Lakes and their intermediate channels and the proposed Niagara ship canal to Lake Ontario, and that the Canadian seaboard may then be reached from Lake Ontario by the way of St. Lawrence River, and the American seaboard reached from Lake Ontario by way of either the Oswego-Mohawk-Hudson route or the St. Lawrence-Champlain-Hudson route. The Deep Waterways Commission was not authorized to make any considerable expenditure for surveys, and hence the conclusions announced are to some degree tentative. In view of the uncertainty as to final cost, it is recommended that the alternative routes from Lake Ontario to the Hudson be subject to complete survey in order to obtain a full development of the governing economic considerations, as well as to determine their relative availability.

The commission also recommends a moderate control of the level of Lake Erie and of Niagara River above Tonawanda by dam, but leaves the practical details undetermined in the absence of a full understanding of the physical conditions.

The river and harbor act of June 3, 1896, directs the Secretary of War to cause to be made accurate examinations and estimates of the cost of constructing a ship canal by the most practicable route, wholly within the United States, from the Great Lakes to the navigable waters of Hudson River, of sufficient capacity to transport the tonnage of the lakes to the sea. Under the provisions of this act a report

was submitted by Maj. Thomas W. Symons, of the Corps of Engineers, dated June 23, 1897.[1]

Major Symons states that there are three possible routes for the ship canal, entirely within the territory of the United States, from the Great Lakes to the navigable waters of the Hudson, as follows:

(1) From Lake Erie via the upper Niagara River to the vicinity of Tonawanda or La Salle; thence by canal, with locks, either to the lower Niagara at or near Lewiston, or to some point on Lake Ontario; thence through Lake Ontario to Oswego; thence up Oswego and Oneida rivers to Oneida Lake, and through Oneida Lake; thence across the divide to Mohawk River, and down that river to the Hudson at Troy; thence down the Hudson. This he designates as the Oswego route. From Oswego to Hudson River it is, in effect, the Oswego-Mohawk-Hudson route, already described.

(2) To follow either the line of Erie Canal from Lake Erie to the Hudson, or this line so modified as to provide for a continuously descending canal from Lake Erie to the Hudson. This he designates as the Erie Canal route.

(3) This route coincides with the first from Lake Erie to Lake Ontario, but runs thence through Lake Ontario to St. Lawrence River and down said river to some point near Ogdensburg; it then crosses the State of New York to Lake Champlain and up that lake to Whitehall; and thence follows in general the route of the Champlain Canal to Hudson River at Troy. This route, however, Major Symons pronounces impracticable.

There is also discussed a fourth route—the St. Lawrence-Champlain—all of which, except a small portion, is within the United States. This route would be via Niagara Falls, Lake Ontario, the St. Lawrence, Caughnawaga, and Richelieu rivers, Lake Champlain, and the Hudson.

The opinion is expressed that the best route for the contemplated ship canal is that via Niagara River, Lake Ontario, Oswego and Oneida rivers, Oneida Lake, and Mohawk and Hudson rivers, and that to build such a canal by any of the possible routes mentioned would, at a rough estimate, cost $200,000,000, the exact figure depending very largely upon the action of the State of New York in regard to the State canals, feeders, reservoirs, etc.; and that to maintain the canal and to keep it in repair, including the maintenance of river channels, reservoirs, and feeders, would cost, at a rough estimate, $2,000,000 a year. The statement is made that a ship canal would be of no special military value, and that its construction is not worthy of being undertaken by the General Government because the probable benefits to be derived from it would not be commensurate with the cost.

Major Symons further expresses the opinion that Erie Canal, when enlarged under the present plans of the State of New York, may

[1] See Ann. Rept. Chief of Engineers for the fiscal year ending June 30, 1897.

give, if State restrictions are removed, commercial advantages practically equal to those to be derived from the proposed ship canal, and that if Erie Canal be further improved by enlargement to a size sufficient for 1,500-ton barges, making such alterations in alignment as to give a continuously descending canal all the way from Lake Erie to the Hudson, and canalizing Mohawk River, the improved canal, navigated by barges, would render practicable the transportation of freight between the East and the West at a lower rate than by a ship canal navigated by large lake or ocean vessels. The difficulty of navigating large vessels through long, shallow canals is the loss of time and the consequent great increase in the pro rata expense account, as compared with the actual amount transported between termini. Major Symons is also of opinion that the enlargement of Erie Canal on these lines is a project worthy of being undertaken by the General Government, because the benefits to be derived would be commensurate with the cost, which he estimates at approximately one-fourth that of a ship canal, or $50,000,000.

Space will not permit abstracting in detail these several interesting reports on ship canals across the State of New York. To understand the subject in all its bearings, reference must be made to the original reports.

The Oswego-Mohawk-Hudson route is discussed in a report by Albert J. Himes in the Report of the State Engineer and Surveyor for 1895.[1]

In this report Mr. Himes expresses the opinion that a sufficient water supply could not be obtained for a high summit level across the divide, and hence the canal must be cut from the level of Oneida Lake through to the corresponding level in Mohawk Valley. In this way he proposes to use Oneida Lake as a storage reservoir from which to discharge water both ways to Oswego and Mohawk rivers. By this plan the surface of Oneida Lake would be raised 10 feet, furnishing 1,100 second-feet continuously for seven months. Without going into detail, the writer can not but believe that the water supply estimated by Mr. Himes is not entirely adequate for the supply of such a canal as has been proposed. If such a canal is constructed, the experience gained in the last seventy-five years ought to teach the danger of small economies in designing the water supply. Experience shows that canal water supplies must be made ample, as otherwise a shortage will result sooner or later.

In a paper on an enlarged waterway between the Great Lakes and the Atlantic seaboard, published by William Pierson Judson, the water supply of the summit level of the Oswego-Mohawk-Hudson route is discussed at length. Mr. Judson considers that it would be entirely proper to take whatever deficiency there might be from the

[1] See report on the Enlarged canal via the Oswego route, by Albert J. Himes, resident engineer, Eastern division, New York State canals. In Ann. Rept. State Eng. and Surv. for the fiscal year ending September 30, 1895.

head waters of the Black River, reservoirs in addition to those now existing being constructed on the Beaver and Moose rivers, tributary to the Black, for the purpose of furnishing this water. He recognizes that the item of adequate water supply for such a canal is vital, and frankly states that if surveys and thorough investigations were to show that the demand for water for such a canal is beyond the capacity of the sources of supply, then the Oswego-Mohawk-Hudson route would be shown to be impracticable, although, as an alternative proposition, he states that it would be entirely practicable to supply the summit level of such a canal from Lake Erie. This, it is pointed out, can be accomplished by a feeder branch taken from the present Erie Canal near Macedon, 12 miles west of Newark, where Erie Canal is now 35 feet above the Rome level. The proposed feeder, instead of stepping down, as does the Erie Canal, can be swung off to the south on higher ground at the necessary elevation, passing along the south side of Clyde River and crossing Seneca River near the Cayuga Lake Outlet. Seneca River is narrowest here, and the feeder could be carried across it in an open trunk on a 40 to 50 foot trestle about 2 miles long. Such a feeder 8 feet in depth and 38 feet in bottom width would carry 1,000 cubic feet per second, or enough, according to Mr. Judson, to meet the assumed needs. On this point, however, the author differs; he can not but think that the summit-level supply as estimated by Mr. Judson at 1,000 cubic feet per second is much too small. Mr. Judson's discussion of the deep-waterway question is further open to criticism in that he does not adequately recognize the economic value of the New York water supplies for use in manufactures.

In a paper read before the American Society of Civil Engineers in 1884, Elnathan Sweet proposed a ship canal through to Lake Erie via present line of the Erie Canal, except that its alignment be rectified to follow the line of the feeder, as proposed by Mr. Judson. The difficulties of making a ship canal on this line are, however, so great that many engineers have considered it absolutely out of the question.[1]

A canal on the Oswego-Mohawk-Hudson route 28 to 30 feet in depth, with corresponding surface and bottom dimensions, will probably absorb all available water of central New York, as well as a considerable portion of Black River. The water powers on Mohawk River at Cohoes will necessarily be made subservient to the exigencies of such a canal, although Mr. Judson, in the paper already referred to, has pointed out how valuable these water powers would be for seven or eight months of the year to the manufacturing cities of the Mohawk Valley. Under this head we may, however, inquire as to how the water power for only seven months of the year would be of any special

[1] See Radical enlargement of the artificial waterway between the Lakes and Hudson River, by Elnathan Sweet: Trans. Am. Soc. Civil Eng., Vol. XIV, pp. 37–139.

value to the city of Cohoes, where, owing to the kind of manufacturing, continuous power three hundred and ten days in the year is required. Cohoes had a population in 1890 of 22,509, and is stated to have grown considerably since, so that in 1897 the population is probably in excess of 25,000. This great development is a result of wise management of the water power, without which there is no reason to suppose that the area on which the city stands would have any greater value than that of the surrounding farming region. A proposition to interfere seriously with the water power at Cohoes can only be looked on by the author as most extraordinary. Indeed, not the least extraordinary feature of the present agitation for ship canals across the State of New York is the entire lack of appreciation—so far as the discussion indicates—of the value to the State of New York of its inland waters.

Aside from the report of Major Symons, the discussion has thus far apparently proceeded on the supposition that the taking of inland waters for navigation purposes was a matter on a par with the taking of agricultural lands for right of way, the economic value of the water for power purposes and the resulting effect on the internal development of the State having thus far been almost entirely ignored.

What the people of the State of New York need to consider first of all is whether the inland waters are not now worth more for manufacturing than they can possibly be worth for navigation purposes. If after investigation it is shown that the water will produce greater income to the people of the State in manufacturing than it will in operating such a canal, then from mere commercial considerations the people ought not to consent to the construction of such a canal. Without having the data at hand for a full discussion, the author, after giving the matter careful consideration, is of opinion that the State of New York can not afford to forego the possibility of developing its manufacturing interest in order to furnish water for the summit level of the proposed Oswego-Mohawk-Hudson deep-water canal. At any rate we should know just what results may be expected before embarking in the enterprise. If, however, after full investigation it appears that the canal water supply can be obtained and the manufacturing interests protected, no reasonable objection can be urged.

In order to justify the construction of the ship canal as a commercial proposition, the saving on the transportation of an estimated annual tonnage of 24,000,000 tons over the cost of its transportation by existing means and methods must, at least, equal the interest on the cost of the canal plus the annual cost of maintenance and operation. The first cost is taken at $200,000,000, with the maintenance at $2,000,000 per year. Assuming an interest charge of 3 per cent, the annual interest plus the maintenance becomes $8,000,000, which sum

represents the annual expense of the proposed ship canal connecting the Great Lakes with the Atlantic seaboard. As regards the State of New York, there should be added to this amount a sum representing the decrease in wealth in central New York due to the absorption of the inland waters of the State away from manufacturing interests in favor of navigation interests. As a rough estimate the author places such decrease at not less than $5,000,000 per year, although the decrease would probably be much greater than this, but in the absence of data for full discussion he places it at a conservative figure, which can not well be gainsaid. On the other hand, if the international St. Lawrence-Champlain-Hudson route were to be constructed, not only would this source of loss be entirely eliminated, but since that plan proposes to deliver water from St. Lawrence River into Lake Champlain, and thence by a through cut from Lake Champlain to Hudson River, there would be delivered into Hudson River a considerable quantity of water which would be available for power at Saratoga dam, Mechanicville, and Troy. This ship-canal project thus increases rather than decreases the productive capacity of the State. Moreover, it is probable that the St. Lawrence-Champlain-Hudson route can be constructed somewhat more cheaply than the Oswego-Mohawk-Hudson route.

Without wishing to present the foregoing as in any degree a final conclusion, the author can not but think that it is the broad view to take of the question. At any rate, this view presents a line of investigation which ought to be pursued to a conclusion before the final decision is made.

LOSS OF WATER FROM ARTIFICAL CHANNELS.

The large amount of canal construction in New York State has necessitated, in order to provide ample water supplies, the collection of considerable information as to the various sources of loss of water to which artificial channels are subject. Some of the more interesting results may be briefly referred to.

The original Erie Canal was constructed with the water surface 40 feet wide, the bottom width 28 feet, and the depth 4 feet. In 1824 measurements of the loss from filtration and evaporation were made by Mr. John B. Jervis on the eastern division and by Mr. David S. Bates on the western division. Mr. Jervis states that his measurements were made in the original Erie Canal, between the first locks below the village of Amsterdam and the aqueduct below Schenectady, a distance of 18 miles. This section was constructed mainly through an alluvial soil, containing a large portion of vegetable matter. In some places this soil was very leaky, owing probably to the decay of roots, although the greater portion retained water very well. There was a considerable quantity of gravel and slaty soils. He states that

the quantity of water lost in this 18-mile section was very uniform, and averaged 125 cubic feet per mile per minute.[1]

Mr. Bates states that his measurements in 1824 showed that a mile of new canal, such as Erie Canal then was between Brockport and Ninemile Creek, would require 1.7 cubic feet of water per mile per second in order to supply the losses from filtration, leakage, and evaporation.[2] The following are some of the details of Mr. Bates's measurements in 1824:

On 79 miles of canal and feeder, comprising 20 miles of canal from Rochester to Brockport, 57 miles from Rochester to Cayuga, and 2 miles of feeder, the supply was 8,000 cubic feet per minute, or 121.66 cubic feet per mile per minute. The months are not stated, although it may be inferred that these observations are averages of the navigation season.

Mr. Bates further states that in August, 1824, he found a total use for the 20 miles from Rochester to Brockport of 2,100 cubic feet per minute, equal to 105 cubic feet per mile per minute. This section of the original Erie Canal was considered to be entirely free from leakage at the structures, and the measured losses are therefore taken as those due only to percolation, absorption, and evaporation.[3]

In August, 1839, Henry Tracy and S. Talcott, acting under instructions from W. H. Talcott, resident engineer of the fourth division of Genesee Valley Canal, made a series of observations along the line of Chenango Canal, with a view of determining the evaporation, filtration, and leakage at the mechanical structures, and whatever else might be useful in the designing of the water supply of the summit level of Genesee Valley Canal.

For the purposes of the measurements they selected a portion of the canal extending from the north end of the summit level to Erie Canal, 22 miles in length, on which the total supply on August 31 was found to be 39 cubic feet per second. The leakage and waste at aqueducts, waste weirs, and at lock No. 1 at the northern end, were found to be 15 cubic feet per second, thus leaving the evaporation and filtration on 22 miles at 24 cubic feet per second, equivalent to 1.09 cubic feet per mile per second. It may be observed, however, that a measurement made at the end of August would probably not show a maximum of either evaporation or absorption by vegetation. Estimating these elements at the maximum, we may assume from 1.33 to 1.67 cubic feet per mile per second as a more reliable quantity than the 1.09 cubic feet per mile per second here actually observed.

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[1] Report of John B. Jervis to the canal commissioners, on the Chenango Canal. Ann. Rept. Canal Com. (1834). Ass. Doc. No. 55, p. 54.

[2] Report of David S. Bates to the canal commissioners, on the Chenango Canal (1830). Ass. Doc. No. 47, p. 31.

[3] See report of F. C. Mills in relation to the Genesee Valley Canal (1840). Ass. Doc. No. 26, p. 26. See also report of W. H. Talcott in the same document. These two reports contain a summary of all that had been done in the way of measurements of the various losses now under discussion up to that time, as well as a number of references to foreign data.

Messrs. Tracy and Talcott also measured the leakage and waste at the various mechanical structures, etc., which were as follows: Leakage at structures, 220 cubic feet per minute; waste at waste weirs, 204 cubic feet per minute; leakage at lock No. 1, at the north end of the section, 479 cubic feet per minute. This amount, Mr. Talcott remarks, was so much greater than at any other lock on the canal as to induce the belief that the gates were not properly closed at the time of measurement. At lock No. 69 on the same canal, the leakage was 382 cubic feet per minute from an 8-foot lift.

Mr. Talcott's report is very able, and presents forcibly all the data at hand at that time. It may be said that the data which he gave fixed the following quantities as fairly covering the various losses to which artificial waterways of the dimensions of the original canals of this State are subject:[1]

(1) Loss by filtration, absorption, and evaporation, 100.0 cubic feet per mile per minute. With retentive soils this could be reduced to from 60 to 70 cubic feet per mile per minute. Mr. Talcott fixed on 66 cubic feet per mile per minute for Genesee Valley Canal, which was largely built through heavy soils, but this was subsequently found too small.

(2) Leakage at mechanical structures; for locks of 11 feet lift, 500 cubic feet per minute; for leakage and waste at each waste weir, 30 cubic feet per minute; for a wooden-trunk aqueduct, an amount depending on the length of the structure, but as an average, 0.35 of a cubic foot for each linear foot of trunk may be taken.

In response to a resolution of the canal commissioners of April 12, 1841, Mr. O. W. Childs, then chief engineer of Erie Canal, prepared a report on the water supply of the western division with reference to the enlargement then in progress.[2] In this paper Mr. Childs gives the results of measurements made by himself in 1841 of losses from filtration, absorption, evaporation, and leakage on the original Erie Canal between Wayneport, in Wayne County, and Pit Lock, which corresponded to lock 53, near Clyde, of the present canal. He also gave the result of measurements made by Alfred Barrett between Pittsford and Lockport.

Mr. Childs's measurements were for a section of the canal 36.02 miles in length. On the Palmyra level, for a distance of 8.34 miles, where the soil is open and porous the measurements showed a loss of 1.81 cubic feet per mile per second. On the Clyde level with a more retentive soil the losses from filtration, absorption, and evaporation were, for a distance of 27.68 miles, only 0.59 cubic feet per mile per second. The entire loss, including leakage, was, for the whole distance, 1.40 cubic feet per mile per second. These measurements were made for

[1] The quantities here given apply to canals 40 feet by 28 and 4 feet deep, and with locks 90 feet in length and 15 feet in width and 8 to 10 feet lift.

[2] See Supply of water required for the canal between Lockport and the Seneca River, by O. W. Childs: Ann. Rept. Canal Com. (1848). Ass. Doc. No. 16, pp. 141-175.

a term of thirty-three days, from July 30 to August 31, inclusive. Measurements were also made in June, early in July, and in the following October, from which the conclusion was derived that demands were greater and the supply less for the time during which the foregoing observations were taken than during any other portion of the season.

Mr. Barrett's measurements were made at various points on the original canal between Pittsford and Lockport, and repeated each day from July 17 to September 30, inclusive. They showed an average loss for the whole period of 73.0 cubic feet per mile per minute. Assuming the same ratio of loss between Pittsford and Wayneport, there resulted, for the entire distance of 122 miles from Lockport to Pit Lock, an average loss of 67 cubic feet per mile per minute. Mr. Childs states that an addition to the foregoing quantity should be made as an allowance for springs and several small streams entering the canal which could not be measured. Making such additions he concludes that 1.42 cubic feet per mile per second should be taken as the total quantity consumed on the 122 miles of canal under consideration, which is equivalent to a total of 173 cubic feet per second. It is stated in the original reports that the supply of water was ample for all the purposes of navigation during these measurements.

Comparing Mr: Childs's measurements of 1841 with those made by Messrs. Jervis and Bates in 1824, one point of great practical utility is strongly brought out, namely, as to the excess of loss of water in new canals over those some time in use; thus Mr. Bates found in 1824, on the same reach of canal as was measured by Mr. Childs in 1841, a total loss of from 1.68 to 1.75 cubic feet per mile per second. It may be assumed that the springs and streams allowed for by Mr. Childs were delivering into the canal in 1824 the same as in 1841, at least 0.17 to 0.25 cubic feet per mile per second. We have, then, as the total supply in 1824 from 1.92 to 2.00 cubic feet per mile per second. Adopting the latter figure as a maximum to compare with Mr. Childs's figure of 1.42 cubic feet per mile per second, as found in 1841, the conclusion is reached that the decrease in the loss by filtration—due presumably to the gradual silting up of the bottom—is something like 0.75 cubic feet per mile per second.

This conclusion may be applied to the conditions of the Erie Canal enlargement now in progress, in which it is proposed to excavate 1 foot from the bottom of many of the levels. The effect of this will be to remove the silt accumulations of many years, thus placing the bottom of the canal, as regards porousness and consequent percolation and filtration loss, in the same condition as when constructed. This consideration alone indicates the necessity of making the water supply of the enlarged canal liberal in order to answer the demands of the first few years while the bottom is again attaining a fixed condition.

Under this head it may be remarked that the experience of seventy-five years in the operation of the New York State canals has thoroughly shown the futility of any attempt at excessive economy in water supply. In the absence of systematic information as to yield of streams, the general tendency has been to overrate the summer flow, with the result of shortage frequently at points where the supply was believed to be ample. The chief sources of such shortage may be enumerated as follows:

(1) The great variation in the yield of drainage areas from year to year, by reason of differences in the rainfall, humidity, and temperature.

(2) The cutting off of forests, which has increased somewhat the spring-flood flows and decreased the summer flow.

(3) The systematic drainage of large areas, which has also tended to increase the flood flows and decrease the summer flows.

(4) The growth of aquatic plants on long levels and the formation of sand bars in the canal, which have tended to decrease the amount passing.

Among minor sources of loss, evaporation and absorption by growing plants may be mentioned, both of which vary somewhat in different years, although neither can be considered a serious source of loss. A number of other measurements of the losses from the original Erie Canal are recorded in the reports, but the foregoing are sufficient for present purposes.[1]

A study of all the measurements in detail shows that in an artificial channel of the dimensions of the original Erie Canal, and constructed on the American system, there should be provided at least 80 to 100 cubic feet per mile per minute, exclusive of water for filling and for lockages.

Using the data of the measurements of 1841, Mr. Childs arrived at the water supply of the enlarged canal of that day in the following manner: It was assumed that the loss by filtration through the bottom and sides of the canal would be as the square root of the pressure or depth of the water, and as the area of the surface pressed. Proceeding on this assumption, he computed the quantity required to supply the losses from filtration, leakage, and evaporation (in the enlarged canal, 1840 to 1860), at 3.17 cubic feet per mile per second. This figure was subsequently substantially adopted for the entire enlarged canal, and, with the exception of a few special cases, is still in use.

Adding the amount required for lockages at lock 53, Mr. Childs placed the entire supply for the western division, from Lockport to the east end, at 3.48 cubic feet per mile per second, or at a total of 424 cubic feet per second for 122 miles of canal.

The canal enlargement now in progress contemplates an increase in

[1] Ass. Doc. (1840), No. 96, p. 26; also Ass. Doc. (1842), No. 24, p. 37.

depth from 7 to 9 feet. Taking into account the results of the measurements on the original Erie Canal, as well as those made by Mr. Childs on the enlarged canal of 1840 to 1860, it has been concluded that the proper figure for water supply on the western division, to which the studies thus far specially refer, should be taken at from 4.17 to 4.5 cubic feet per mile per second.[1]

As to the use of water for lockage, leakage of gates, drawing and swelling of boats, and for turbine water wheels to operate gate-lifting machinery, reference may be made to the Annual Report of the State Engineer and Surveyor for 1889, where data covering these different points may be found.

Ordinarily, the flow of a natural drainage channel increases farther down the stream. The outlet of Skaneateles Lake, however, appears to present an opposite example—that is to say, there is less water flowing at the mouth of the stream than at its head. This statement is derived from a report on the water supply of the middle division of Erie Canal, made in 1862,[2] according to which measurements were made by Mr. S. H. Sweet of the flow through the natural channel of the Skaneateles Outlet, 10 miles in length, discharging into the Erie Canal at Jordan. Mr. Sweet's measurements, which were continued through the dry season of 1859 and the entire season of navigation, apparently indicated a loss of water of more than 3,000 cubic feet per minute in this natural channel. The detail, however, is lacking, and probably before accepting this as a fact the measurements made in 1859 should be verified.

USE AND VALUE OF WATER POWER.

WATER POWER OF ERIE CANAL.

When Erie Canal was first constructed the policy was adopted of leasing the so-called surplus waters for power purposes. Under the terms of the act of 1825, leases were made during 1826 and subsequent years to a number of persons at Black Rock, Lockport, and other localities.

POWER AT BLACK ROCK.

The granting of these leases and the resultant development of large manufacturing interests at several points have raised certain economic questions which will now be briefly discussed. The water power at Black Rock, for which several leases were granted, may be first mentioned. This power is created by the difference in level between the water in Erie Canal and Black Rock Harbor and that in Niagara River outside the harbor wall, this difference of water level

[1] The foregoing statements in regard to measurements of water supply of Erie Canal are abstracted from a report on the water supply of the western division of the Erie Canal, by the author, and are to be found in Appendix I to the Ann. Rept. of the State Eng. and Surv. for the fiscal year ending September 30, 1896.

[2] See Ann. Rept. of State Eng. and Surv. for the fiscal year ending September 30, 1862, pp. 402, 403.

amounting to from 4 feet to 4.5 feet. As measured in the spring of 1896, at a point near the ship lock, it was about 4 feet. According to the report of the assembly committee of 1870, as referred to in the footnote, there were formerly ten mills in operation at Black Rock, using 2,744 second-feet of water. The power developed by these mills, and all operating at full capacity, is estimated at not exceeding 520 horsepower. Owing to the decline of the milling business in New York State a number of these mills have passed out of existence.

The four mills still in existence require about 1,200 cubic feet of water per second to operate them at the full capacity of the wheels now in place.

The use of water by the Black Rock mills has always been a detriment to navigation. When all were running the amount of water actually drawn through the canal and harbor for their supply, and for the supply of the canal to the east of Buffalo, was fully 3,300 cubic feet per second.[1]

When all the Black Rock mills were in operation the great draft of water so obstructed the navigation that the legislature finally authorized the construction of a division wall in Black River Harbor, by which it was expected that the water supply for the mills would be entirely taken from the harbor, leaving the channel of the canal pretty nearly free for the purposes of navigation; but after the greater part of the wall was completed it was ascertained that because of the silting of the upper harbor with sewage mud, as well as drifting sand from the lake, there would be difficulty in obtaining the full supply for the mills through the harbor, without extensive dredging. The division wall was, therefore, never completed, two gaps, amounting, in the aggregate, to several hundred feet, having been left below Terry street. There was thus an expenditure of about $350,000 for the benefit of the milling interests which is entirely without effect for lack of completion. Under the present conditions, however, of entire decline of the Black Rock milling interests, there is, of course, no reason why the wall should be completed, and the matter is discussed here at all merely for the purpose of bringing out clearly the struggle between the navigation interests and the manufacturing interests, which has been in progress in New York State for the last seventy-five years.

POWER AT LOCKPORT.

At Lockport the construction of the Erie Canal through the mountain ridge created a fall of 58 feet at a single point, and since the use of water for lockage purposes is only a small part of the whole flow. The balance required to feed the canal to the east of Lockport is necessarily discharged around the locks into the lower canal by means of

[1] The assembly committee of 1870 give the following figures as then applicable: Lower Black Rock mills, 1,887 second-feet; upper Black Rock mills, 858 second-feet; for supply of canal, 583 second-feet; total, 3,328 second-feet.

sluiceways. Under the provisions of the laws of 1825, a public auction was held in the village of Lockport, in the fall of that year, and the right to use this surplus water sold to Messrs. Richard Kennedy and James H. Hatch, whose successors at the present day constitute the Lockport Hydraulic Power Company.

Lockport has usually been considered more purely a result of the canal development than any other point in western New York, for the reason that while nearly all other towns in the region had some growth before the Erie Canal was located, it was only in 1821, after the present location for the canal had been definitely decided on, that the nucleus of a village was formed here by the contractors and their workmen employed on the canal. In 1820 there was no frame house or barn within 5 miles of Lockport, and there were less than 600 acres of cleared land in the 4 square miles, of which the city of Lockport is now the center. Moreover, there are no natural advantages which would have naturally led to the growth of an important town at this point. The water supply of the region is so deficient that even to this day the city takes its public supply from Erie Canal, which is grossly polluted with sewage from the city of Buffalo. It may be considered, therefore, that the city of Lockport owes its existence entirely to the creation by Erie Canal of a large water power at this point.

When once started, however, under the impulse of the canal development, Lockport grew rapidly until, in 1829, with a population of 3,000, it was incorporated as a village, and in 1865 as a city. The population in 1890 was 16,038; in 1897 it is estimated at over 17,000.

The total investment in manufacturing plants at Lockport dependent on the Erie Canal water supply amounts to $2,531,000. The total number of establishments is 33, employing 1,880 operatives. The total power now in use on Erie Canal proper is 2,625 net horsepower.

A short distance to the east of the foot of the locks a small stream known as the West Branch of Eighteenmile Creek crosses under the canal. This stream, although having a drainage area of only 1 or 2 square miles to the south of the canal, has cut a deep valley with rapid fall for a considerable distance to the north of the canal. In order to provide for discharging the surplus waters from the canal, an overflow into Eighteenmile Creek was constructed at an early day. A mill was also permitted to take water from the lower level and discharge its tail-water into the creek. Finally the Jackson Lumber Company was permitted to construct a sluiceway on the towpath side, through which it drew for many years about 600 second-feet, and which was all discharged into Eighteenmile Creek. Complaints having frequently been made that boats were drawn against this sluice on the towpath side, the superintendent of public works, in 1892, granted a formal permit to the Jackson Lumber Company to construct a sluice and subway under the canal bottom, by which this water is now drawn from the berme side. Under this permit a substantial

masonry sluice was constructed in 1893. In the meantime the Jackson Lumber Company has gone out of existence, and this water power has passed into the hands of the Traders' Paper Company, which now occupies the site with its pulp mill No. 1.

West Branch of Eighteenmile Creek descends about 175 feet within the limits of the city of Lockport, of which 148 feet have been utilized for power during recent years.

The following are the companies now using power on this creek and the horsepower used by each:

Power utilized on West Branch of Eighteenmile Creek.

	Horsepower.
Traders' Paper Company	1,060
Lockport Paper Company	230
Niagara Paper Company	115
Westerman and Company	320
Cascade Pulp Company	925
Cowles Smelting Company	1,185
Total	3,835

The output of the establishments on West Branch of Eighteenmile Creek is about $2,000,000 a year; but this sum includes the output of the Indurated Fibre Company, which, while operating by steam power, depends largely for a supply of pulp on the Cascade Pulp Company. In any case, the figures show the magnitude of the manufacturing interests which have been fostered in the valley of West Branch of Eighteenmile Creek, by discharging into that stream about 300 second-feet of water from the Erie Canal.

With 2,625 net horsepower in use on the canal proper, and 3,835 on West Branch of Eighteenmile Creek, the total actually in use at Lockport, and dependent on Erie Canal for its water supply, is 6,460 net horsepower.

No statements as to the value of the annual product of the manufacturing establishments on the raceways of the Lockport Hydraulic Power Company have been given. It is therefore impossible to state accurately the value of the total annual product at Lockport. As several of the establishments there are very extensive, including the Holly Manufacturing Company, it may be assumed that the annual output of this portion of the Lockport manufactories has a value, at least, of $1,000,000; hence we reach a total value of the annual product for the whole city of about $3,000,000.

The annual rental paid to the State, under the terms of the original lease, is only $200. At first sight it appears that there is here a most marked case of what could only be termed blundering on the part of State officials, although on analyzing the matter it is found that this extreme view is hardly correct. In the first place it must be remem-

bered that this lease was granted not only by authority of an act of legislature, but was only granted after a public auction had been held, at which Messrs. Kennedy and Hatch were the highest bidders. As already shown, had not the special conditions created by Erie Canal existed at Lockport, there would, in all probability, have been no thriving city at that point, but the area on which Lockport now stands would have been farming land, with no more value than now attaches to farming lands in the adjoining township of Lockport.

In order to show the results of this lease, at $200 a year, a study has been made of the growth of Lockport from the year 1865, when Lockport became a city, to 1896. It appears, for instance, that the valuation of the city has increased from less than $3,000,000 to over $6,700,000, and that the total State tax collected up to and including the year 1896 has amounted to over half a million dollars. If this had remained as a small farming community the State tax would probably not have been more than 3 per cent of this amount. Using this tax return as a basis, it has been computed that there has been an actual increase of wealth to the people of the State by the existence of Lockport of over one and a half million dollars, not including in this the actual increased value of the city itself. The conclusion is drawn that the benefit to the State at large has been very great on account of this expenditure for internal improvement, irrespective of questions of navigation.

POWER AT MEDINA.

The Oak Orchard feeder and the water power at Medina present somewhat different points for consideration from those at Lockport.

About 1820 the canal commissioners caused a cut-off channel to be constructed through Tonawanda swamp between Tonawanda and Oak Orchard creeks, whereby the early summer flow of Tonawanda Creek is diverted into Oak Orchard Creek. Oak Orchard Creek passes under the Erie Canal at Medina, and the original feeder channel at that place was an artificial channel leading from a dam thrown across the creek and entering the canal near West Branch of Oak Orchard Creek at Medina. At some period subsequent to 1823 a race way was constructed by private parties leading from a second dam higher than the feeder dam and conducting water into the central part of the village, where, after it is used, it is finally allowed to pass into the canal. During the enlargement of 1836 to 1862 the water-surface level of the canal at Medina was raised, and inasmuch as this change necessitated raising the feeder dam somewhat, it was finally concluded to discontinue the feeder and depend entirely on the race way for such supply as the canal might receive at this point.

Oak Orchard feeder has been considered as furnishing about 27 cubic feet of water per second to the canal, although measurements made in 1850 show about 37 cubic feet per second. Since then the clearing up of forests and the drainage of Oak Orchard and Tona-

wanda swamps have tended to reduce materially the low-water flow until it is probably less than 27 cubic feet per second. Moreover, for the future, the dry-weather yield from this drainage area may be expected to be somewhat less than in the past, because of the deepening of the channel of Oak Orchard Creek and of the crosscut authorized by the laws of 1893. The act provided for deepening the channel of Oak Orchard Creek from a point 2½ miles below where Tonawanda Creek enters the Oak Orchard and for the cleaning, improving, widening, and deepening of the channel of East Branch of Oak Orchard Creek. This work has been done as a sanitary measure, and its effect will probably be to run the water out of the swamps more rapidly in the spring, thus materially decreasing the dry-weather flow.[1]

According to a statement furnished by Mr. A. L. Sweet, president of the Business Men's Association of Medina, the number of operatives employed in 1896 in manufacturing enterprises dependent on water power at Medina was 515; the amount of capital invested in establishments actually in operation was $371,000, while the value of the annual product of the same establishments was $575,000. These figures do not include the Medina Falls flouring mill, which was idle at the time these statements were made.

The total developed water power at Medina, on the race way and on the Oak Orchard Creek, is estimated at 827 horsepower, which includes the wheels at Medina Falls flouring mill. Deducting these wheels, amounting to 338 horsepower, the total actually in use in 1896 is 489 horsepower. The use of water at the establishments on the creek varies from 110 cubic feet per second to 49 cubic feet per second, the former quantity being due to the Medina Falls flouring mill, where the head is 33 feet. Relative to the fine power at Medina Falls, it may be stated that it is improbable, considering the amount of power available at this location, that it will remain unutilized for any great length of time. The trouble at Medina Falls flouring mill is the same as that affecting the large flour mills at Black Rock and other places in New York—the competition of cheap grain and transportation from Western mills.

Without going into the historical part of the subject, it may be said that the mill owners at Medina claim that by reason of the granting of a right of way for the cut-off between Tonawanda and Oak Orchard creeks, and the gift of 100,000 acres of land to the canal fund by their original grantor, the Holland Land Company—a part of the consideration for which was an improvement of the water power of Oak Orchard Creek—they have an equitable right to the use of the water of the feeder. If, therefore, the effect of the drainage authorized by the laws of 1893 has been to decrease the low-water flow of

[1] For extended account of Oak Orchard Creek and its relations to the feeder, see Report on the drainage of the Oak Orchard and vicinity streams, in the Fourth Ann. Rept. of the State Board of Health (1883), pp. 43-116.

Oak Orchard Creek, it is maintained that the mill owners are entitled to enough water from the canal to make good the deficiency.

There are a number of other points on the Erie Canal where water powers have been fostered under the provisions of the laws of 1825, but lack of space precludes discussion of that phase of the subject.

SELLING PRICE OF WATER POWER.

The principal places in New York State at which hydraulic developments have thus far been made for the purpose of selling power are Oswego, Cohoes, Lockport, and Niagara Falls. At Oswego the power on the east side of the river is owned by the Oswego Canal Company, the development being by a canal 4,000 feet long, with an average surface width of 60 feet and a depth of 6 feet. The water from this canal is dropped into Oswego River at the level of Lake Ontario. The working head is from 18 to 20 feet, although with high water in the canal and low water in Lake Ontario, the working head becomes somewhat greater.

The State controls the first right to the flow of Oswego River in order to maintain slack-water navigation in the pool above the dam at the head of the Oswego Canal Company's race way, all water not needed for canal purposes being equally divided between the Oswego Canal Company's race on the east side and the Varick Canal on the west side. The Oswego Canal Company gives a 999-year lease of water, but without land for location of buildings. A water right on this canal is called a run, meaning, probably, the amount of water required to drive a run of stone, a run of water being taken at 11.75 second-feet which, under the ordinary working head of 20 feet, will, at 75 per cent efficiency, produce 20 horsepower. There are assumed to be 32 first-class runs, the rental for which is $350 a year for each run. At this price the cost of a horsepower a year, with 75 per cent efficiency, becomes $17.48, or the cost of a gross horsepower a year becomes $13.11. There are also 32 second-class runs, of which the rental varies from $250 to $300 a year for each run. Further, there are surplus runs which are rented at a little over one-half of the rental charged for first-class runs. In case of a shortage of water the surplus runs are shut down successively, beginning with the most recent leases; after this the second-class runs share equally with one another in reduction; and finally, in case of extreme shortage, the first-class runs are similarly cut down.

The Varick Canal on the west side of the river controls one-half of all the water not needed for navigation purposes, the same as the Oswego Canal Company's canal on the east side. In order that the water may be divided equally between these two canals both have the same aggregate waterway at the head gates, and by gages on both sides, which are examined whenever necessary, it can be seen whether one canal is drawn below the other, and the gates changed accord-

ingly. On this canal there are recognized 50 first-class runs, 17 second-class, and an unlimited number of third-class. For first-class runs the rental is from $250 to $300 per annum; for second and third class it ranges from $125 to $150. By a decree of the supreme court, dated August 21, 1875, a run of water on the Varick Canal ranges between 28 cubic feet per second, under a head of 12 feet, and 25 cubic feet per second, under a head of 13 feet. The actual working head is, however, ordinarily only about 10 feet, so that on the foregoing basis a run of water may be taken as 33.3 cubic feet per second. At the price of first-class runs of from $250 to 300, and with 75 per cent efficiency, the cost per horsepower per annum varies from $8.80 to $10.56, a run on the Varick Canal being equal to 33.3 cubic feet per second on 10 feet head, an amount of water which yields 37.9 horsepower under that head.

As to the difference in cost of water on these two canals at Oswego, it may be pointed out that the Oswego Canal Company's race has a substantial advantage over the Varick race, in that it extends to the harbor, enabling vessels to come directly alongside of the mills. Moreover, the division of water rights is such that a first-class run of water can always be depended on along the Oswego Canal Company's race, but can not on Varick Canal.[1]

At Cohoes we have the great power development built up by The Cohoes Company, which has, by careful management of the water power, built up at this place a fine manufacturing city of 25,000 inhabitants. Lack of space will not permit description of this development in detail.

The Cohoes Company not only owns all of the hydraulic canals, but also the land adjoining the canals. It gives to manufacturers a perpetual lease of land and water, the entire property leased remaining subject to a rental of $200 per year per mill power. On this basis the land is regarded as donated and the rental applies only to the water power. Formerly, the standard for measuring water was 100 square inches, to be measured through an aperture in a thin plate 50 inches wide, 2 inches deep, and under a head of 3 feet from the surface of the water to the center of the aperture; but in 1859 a series of measurements were carefully made under the direction of the late James B. Francis, using an old canal lock as a measuring chamber. These measurements showed that the old standard corresponded to about 5.9 cubic feet of water per second. As a result 6.0 cubic feet of water per second, under 20 feet head, was taken as a new standard constituting a mill power. On this basis a mill power is equivalent to 13.63 gross horsepower, which, at $200 per mill power per annum, costs $14.67 per gross horsepower per annum. At 75 per cent efficiency the annual rental for water for net hrrsepower becomes $19.57. In

[1] For additional detail of the water power at Oswego, see Report of Water Power of the United States, Tenth Census, Vol. I, pp. 24–27.

regard to just what is paid for by the annual rental, both at Oswego and Cohoes, it may be remarked that the foregoing prices are for water in the race way, the company maintaining the dams, head works, and main race ways, the lessee taking the water at the face of the race way and maintaining his own head gates, flumes, bulkheads, wheels, and any other appliances necessary for utilizing the water in the production of power.

The water power at Lockport, owned by the Lockport Hydraulic Company, is formed by the drop of the surplus water of the Erie Canal through a distance of 58 feet. A run of water at Lockport does not appear to be very well defined, but the rental charge ranges from $12.50 to $16.67 per effective horsepower. So far as known to the author, just what constitutes an effective horsepower has not been defined.

At Niagara Falls the rental price of undeveloped hydraulic power has been fixed at from $8 to $10 per gross horsepower per annum, the party renting the power taking the water at the face of the head race and making its own connection with the discharge tunnel. Electric power by a two-phase alternating current as it comes from the generator is sold in blocks of 2,000 or 3,000 horsepower, at $20 per net horsepower per annum, the purchasers furnishing transformers, motors, and all other electric appliances. In small blocks the price has been fixed somewhat higher.

A small amount of power has also been sold at different times at Rochester, but since the power at this place is nearly all held by manufacturers who use it at first hand, nothing like a fixed price has been made at Rochester. Generally, power rented has been in small quantities and in connection with floor space, the rental price being really for floor space with small power furnished. Reckoning on this basis, small powers have frequently been rented at Rochester at as high a price as $100 per horsepower per year, this being for power on the shaft, all expenses of maintaining wheels, transmission shafts, etc., being borne by the owner.

The electric companies at Rochester furnish electric power in small blocks at 3 cents per electric horsepower per hour, which, on the basis of ten hours a day and three hundred and ten days a year, becomes $93 per electric horsepower per annum.

STATE OWNERSHIP OF INLAND WATERS.

Without going into a detailed discussion as to State ownership of inland waters in New York, attention may be called to a few of the more essential facts. The absolute ownership by the State of the beds and banks and water flowing in the Hudson and Mohawk rivers has been confirmed by repeated decisions of the highest courts of the State. By reason of the peculiar circumstances of the early settlement of the country the English common-law rule applies to all the

streams of the State except the Hudson and Mohawk, from which it results that all other inland streams are owned to the thread of the stream by the abutting proprietors.

Owing to a confusion of ideas—largely on the part of citizens appointed to the position of canal appraisers, where they exercised to some extent judicial functions—there arose in the early days a broad claim of State ownership to inland waters tributary to the Erie canal. The claim was, however, finally decided in the negative. This condition has, in the case of Genesee River, worked great injustice to the riparian owners, in that under a claim of temporary diversion and an assumed right of permanent appropriation by a statutory enactment declaring the stream a public highway no adequate damages have ever been paid for the diversion actually made from the stream for many years.

A similar lack of appreciation of the real relations of the State to individual citizens in regard to common rights in running streams has apparently led to the enunciation of a course of action on the part of canal officials which, to some extent, in effect confiscates private property.

In the case of Black River the State has extensively adopted the method of compensation in kind rather than compensation in money. In view of the large development of storage on Black River, under the provisions of chapter 181 of the laws of 1851, in excess of what is really required there actually to make good the diversion during the low-water season, and, further, by reason of the State's finally placing the management of the principal reservoirs there in the hands of a commission of owners and users of water power, as provided by chapter 168 of the laws of 1894, it may be assumed that as regards Black River, the State has adopted the policy of conservation of water power, such policy being in line with the best thought of the present day.

In the case of Skaneateles Lake there was for several years a struggle between the State and the city of Syracuse as to the right of that city to obtain the municipal water supply from Skaneateles Lake, the extraordinary feature of that controversy being the assumption on the part of the agents of the State that the municipalities of the State, even in the important matter of public water supply, had no rights which the State apparently was bound to respect.

It may be pointed out that the considerable diversity of law and policy, in regard to the rights of riparian owners thus shown to exist in the State of New York, can not operate other than to discourage the full development of the State's natural resources. What is greatly needed, therefore, in the State of New York is a consistent policy of some sort as between the State, the navigation, the manufacturing, and all other interests, in which each shall receive proper consideration. Thus far navigation interests have usually been placed first,

although it is clear that had there been a more thorough balance, the State as a whole would have been considerably in advance of its present position.

FUTURE USE OF WATER POWER IN NEW YORK.

In the foregoing pages we have seen that the Erie Canal was a development from the necessities of commerce, not only for the State of New York, but, as a means of connecting the Atlantic Ocean with the waters of the Great Lakes, for accelerating the industrial development of the Northwestern States. However, in the nineteenth century events move rapidly, and what was true of the Erie Canal thirty to fifty years ago is not necessarily true to-day. Railway systems have now developed to such completeness as to compete successfully with water transportation by a channel of the size of the Erie Canal. The Erie Canal, therefore, has no longer an indispensable place in our transportation system. Apparently it should either be radically enlarged, with entirely new methods of management, or else abandoned in favor of a ship canal along other routes.

During the period covered by the rise and decline of the Erie Canal as the important factor in through transportation between the East and a large portion of the West the economic conditions of the interior portion of New York have entirely changed. Cheap transportation, by way of Erie Canal and the Great Lakes, has led to a phenomenal development of agriculture on the broad plains of Minnesota and the Dakotas, where, by the use of modern agricultural machinery, grain can be raised at a profit at such prices as to drive the New York grain grower from the market. The cheap transportation afforded by the Erie Canal has, therefore, to a considerable degree, led to the passing of supremacy from the hands of the Eastern farmer, a loss which can only be regained by the development to the fullest extent of the manufacturing industries of New York, thus making a home market for farm products that can not be transported a long distance, such as garden truck and small fruits. The people of the State of New York can purchase the Western breadstuffs as cheaply as they can be produced at home, and this condition is likely to continue indefinitely.

The long supremacy of the navigation interests has moreover led to the incorporation in the law, jurisprudence, and public policy of this State of certain rules of action as to the right to use the water of inland streams, which have tended to discourage the full development of manufacturing interests which now appears desirable, although the author views with satisfaction the rapid change of public sentiment now taking place on these questions. That manufacturing industries by water power are rapidly increasing in the State is made sufficiently clear by the following statistics:

According to the United States censuses of 1870 and 1880 the total developed water power of the State of New York was, in 1870, 208,256

horsepower; in 1880, 219,348 horsepower; increase in the ten years, 11,092 horsepower. The increase in ten years of 11,092 horsepower is equivalent to an increase of 5.4 per cent. The United States census of 1890 did not include any statistics of water power, and it is impossible therefore to state definitely the horsepower in that year; still, taking into account the great increase shown by the special investigations on Hudson River in 1895, on Genesee River in 1896, and at Niagara Falls in 1897, and also considering the advances in paper making—a water-power industry—as well as the great development now taking place at Massena, the increase for the whole State from 1880 to 1900 may be estimated at about 120 to 140 per cent. On this basis there will probably be in use in New York State at the close of the nineteenth century a total water power of something like 500,000 gross horsepower. The manufacture of mechanical wood pulp alone consumes about 125,000 gross horsepower. These figures, while very suggestive as to the future, are nevertheless rendered more pertinent by considering that with full development of the water-storage possibilities of the State, as well as the possibilities of power development on Niagara and St. Lawrence rivers, we may hope ultimately to reach a water-power development in the State of New York something like the following:

Possible development of water power in New York.

	Gross horsepower.
Streams tributary to Lake Erie	3,000
Niagara River (in New York State)	350,000
Genesee River and tributaries	65,000
Oswego River and tributaries	40,000
Black River and tributaries	120,000
Other tributaries of Lake Ontario	10,000
St. Lawrence River	400,000
Oswegatchie, Grass, Racket, St. Regis, Salmon, Chateaugay, and other streams tributary to the St. Lawrence	150,000
Saranac, Ausable, Lake George Outlet, and other streams tributary to Lake Champlain	40,000
Hudson River and tributaries, not including Mohawk River	210,000
Mohawk River and tributaries	60,000
Streams tributary to Allegheny River	5,000
Streams tributary to Susquehanna River	25,000
Streams tributary to Delaware River	30,000
Water power of Erie Canal	10,000
Total	1,518,000

But 1,518,000 gross horsepower has an effective productive value in manufacturing of say $100 per horsepower per annum, or the inland waters of this State have an ultimate economic value, when fully developed, of at least $151,800,000 per annum. They may therefore be considered, in producing capacity, substantially equal to the entire agricultural product of the State in 1890, which, according to the United States census of that year, amounted to a total of $161,593,009.

Indeed, taking into account that agricultural values are continually depreciating, and water-power values appreciating, it is probable that ultimately, if New York State agriculture remains on the same basis as at present, the water-power values will considerably exceed the agricultural values. It is probable, however, if the manufacturing industries of this State are ever so far developed as to bring water power into use to the extent of 1,518,000 gross horsepower, that the local demand for agricultural products will have considerably changed the present downward tendency. As an off-hand figure, we may, therefore, place these two values, at some not very distant date, as equal, and aproximating about $200,000,000 per annum.

OBSTRUCTIVE EFFECT OF FRAZIL OR ANCHOR ICE.

A very serious difficulty in operating water powers on many of the more rapid streams of this State is that caused by the formation and agglomeration of frazil and anchor ice, and probably there is no subject in connection with water-power development which presents so many difficulties as this. So far as can be learned, nothing has been done in the State in the way of studying these phenomena, although the water powers on many New York streams are reported as subject to interruption nearly every year on account of the formation of frazil and anchor ice. The way to find a remedy is first to ascertain all that can be learned in regard to the difficulty to be overcome. From this point of view it is deemed proper to include herein a short account of studies of frazil and anchor ice made in the neighboring Dominion of Canada.

Under the direction of John Kennedy, chief engineer of the harbor commissioner's works at Montreal, very extensive studies of the formation of frazil and anchor ice have been made. The terms "frazil" and "anchor ice" have been used synonymously, and are apparently often understood as the French and English words for the same thing, but the following from the Report of the Montreal Flood Commission of 1890 will serve to define the difference. According to this report, frazil is formed over the whole unfrozen surface wherever there is sufficient current or wind agitation to prevent the formation of border ice; whereas the term anchor ice includes only such ice as is found attached to the bottom. Frazil is frequently misused by being made to include ice formed on the bottom, as well as throughout the mass and on the surface of a river, although properly it should be only applied to floating ice. The common theory has been that anchor ice first forms on the bottom, subsequently rising. The Montreal studies, however, show that this is hardly true. At times the whole mass of water from surface to bottom is filled with fine needles which actually form throughout the water mass itself.

As to the remedy, the studies are hardly complete enough to indicate the best course to pursue. As practical hints, it may be stated

that in locating dams on streams specially subject to this difficulty they should be placed with reference to as long a stretch of backwater and as great depth as possible, all the studies thus far made tending to show that the formation is most extensive in shallow, rapid-flowing water. Usually trouble from frazil and anchor ice extends through a period of a day or two; and at very important plants, where even a short interruption would be a serious matter, arrangements may be made for using steam at the head works for keeping the racks open. This plan has been successfully pursued at the waterworks intakes of several of the Great Lake cities. In the case of power plants, where much larger quantities of water are required and the stream flows with greater velocity, the amount of steam required may be found to be very large.[1]

WATER YIELD OF THE SAND AREAS OF LONG ISLAND.

Long Island is about 114 miles in length, with a varying width of from 10 to 20 miles. Its watershed line consists of a regular ridge of low hills running from New York Bay to the eastern extremity of the island. The highest points of this ridge are about 350 to 390 feet above sea level. This ridge, which is believed to be a part of the terminal moraine of the great glacier, consists mainly of compact drift and bowlders, running at times into clay and coarse gravel. The considerable number of small ponds along the ridge evidence the compactness of its surface material. The slopes and spurs of the central ridge run into Long Island Sound on the north, making an irregular shore line, broken into bays and low headlands. On the south side the slopes lose themselves in a grassy plain sloping gently toward the coast. In its widest part it is called the Hempstead Plains, and stretches for a distance of from 5 to 15 miles between the foot of the central ridge and the Atlantic shore, which is very regular in its outer beach line; but an inner and more irregular beach exists, formed by the shallow waters of Jamaica and Hempstead bays. The Atlantic shore does not anywhere touch the slope of the central ridge, but is separated from it by the wide gravelly plain just referred to.

Numerous small brooks originating on the south slopes of the central ridge cross the gravelly plain, delivering their waters to the Atlantic. On the largest of these brooks gristmills were established at an early date, with ponds of from 8 to 40 acres of water surface and from 5 to 9 feet depth of water.

The fall at these dams rarely exceeds 8 feet. The original municipal water supply of the city of Brooklyn, as constructed about 1856 to 1859, had its source in the Hempstead Plains, several of the large brooks flowing from the central ridge to the Atlantic being appropri-

[1] For reference to the literature of frazil and anchor ice see (1) Report of the Montreal Flood Commissioners of 1886; (2) Reports of the Harbor Commissioners of Montreal for the years 1885, 1887, and 1895; (3) Paper on Frazil ice and its nature, and the prevention of its actions in causing floods, by George H. Henshaw, Trans. Can. Soc. C. E., Vol. I, Part I, pp. 1-23; and (4) Paper on the Formation and agglomeration of frazil and anchor ice, by Howard T. Barnes, in Canadian Engineer, Vol. V (May, 1897).

ated for this purpose. A distributing reservoir was established on the central ridge at an elevation of 170 feet above tide, with the water of the brooks forced thereto by pumping. These brooks were all mainly fed by springs delivering directly into their ponds and channels. The length of these water courses from where the water was taken to the summer sources rarely exceeds 4 miles. In the original construction the waters of these ponds were conveyed by small branch conduits to a large main conduit extending from the most easterly pond or reservoir to the pump well at the engine house, which was located at the foot of the ridge on which the Ridgewood distributing reservoir was situated, not far from the east line of the city of Brooklyn. The main conduit was so located that the water flowed to the engine house by gravity. The following are the statistics of the six ponds originally taken for the Brooklyn city supply, the minimum deliveries here given being as ascertained by measurements during the months of September and October, 1856 and 1857. The figures represent the natural delivery of each stream at its lowest stage of water, and do not include any encroachment upon the stored water which each pond retained, when full.

Area of surface, minimum flow, and elevation of overflow of six ponds originally taken for the Brooklyn city supply.

Pond.	Area of surface (acres).	Minimum flow (cubic feet in 24 hours).	Elevation of overflow above tide (feet).
Jamaica	40.00	419,315	7.90
Brookfield	8.75	265,098	15.40
Clear Stream	1.07	100,448	11.50
Valley Stream	17.78	325,291	12.80
Rockville	8.00	353,388	12.60
Hempstead	23.52	1,054,713	10.60

The same streams were measured in October and November, 1851, and the aggregate result then was 3,137,500 cubic feet. With the exception of Clear Stream, they were again measured in October, 1852, the result then being 2,606,300 cubic feet in 24 hours.

According to a survey made by Theodore Weston in the fall and winter of 1859, the drainage area of the streams originally taken for the municipal supply of Brooklyn was found to measure 46.8 square miles, but subsequent measurements have placed it at 49.9, which is the figure now used.[1]

As already stated, the drainage grounds lie mainly on the Hempstead Plains, although a small portion may be considered as lying on the southern slope of the central ridge. The ridge slopes are composed of clay and alluvial earth, with little power of retaining

[1] As to the difficulty of determining just what the drainage area of any one of these streams actually is, see I. M. De Varona's History and Description of the Brooklyn Waterworks, 1896.

water. Hempstead Plain, on the other hand, consists of a very uniform deposit of sand and gravel with occasional thin veins of clay; hence Hempstead Plain is largely receptive and retentive of water. The sand and gravel on this plain serves two purposes as regards the rainfall sinking into it: (1) It retains the water, only gradually delivering it to the surface in the valleys of the brooks or on or near the seashore in the form of springs; (2) it filters and purifies it, the gravel and sand performing the function of a natural filter bed. It is considered that but a small portion of the ground water of this gravel plain has been derived from the rainfall of any single year. The greater portion of it is considered to have collected during a series of years. Borings and open wells show that this ground water has a nearly uniform inclination toward the south shore of about 12 feet per mile.

Upon the low ridges lying between the several streams crossing Hempstead Plain the inclination of the ground water varies with the width of the ridge, and is steeper in these parts than on the main slope toward the sea, the resistance of the retaining material there being proportionately less. So long as the slope of the ground water is left undisturbed by pumping, as from a series of wells, the permanent slope of the ground water is determined by the resistance of the material through which it flows. As regards the minimum flow of the streams receiving these underground waters, the longer the time occupied by that portion of the rainfall which sinks into the ground in reaching the outlets the greater will be the minimum flow of the stream as compared with its total flow; on the other hand, the shorter the time the smaller the minimum flow. In the case of the Long Island streams the minimum flows are not very large, a fact which indicates that the permanent regimen of these streams is probably maintained by the accession of the absorbed rainfalls of several years. It follows that so long as the basins are not drawn upon very greatly in excess of their flowage capacity the permanency of Long Island ground water supplies is only moderately affected by variations in the yearly rainfall.[1]

The water supply of the city of Brooklyn has frequently been increased in order to meet the necessities of the constantly increasing population. Additional drainage areas have been taken, and open wells and driven-well systems have been constructed and additional streams and ponds appropriated. At present there are a number of deep open wells, each about 50 feet in diameter, and several driven-well stations. For details of the original conduits, ponds, and streams reference may be made to a description of the Brooklyn waterworks in Water Power of the United States, Tenth Census, 1880, Volume XVII, as well as to the histories of the Brooklyn waterworks.

[1] The foregoing statements relating to the water-yielding properties of the Long Island sands are mostly derived from Kirkwood's History of the Brooklyn Waterworks and Sewers, published in 1867. For a more recent, as well as more extended, discussion of the same subject see De Varona's History and Description of the Brooklyn Waterworks.

In a report on the future extension of the water supply of Brooklyn, by Mr. I. M. De Varona, engineer of the water supply, transmitted to the common council, January 31, 1896, tables are given of the total monthly and average daily quantities of water pumped into the Ridgewood reservoir for the years 1860 to 1895, inclusive.

The accompanying table has been condensed from this report, giving in calendar years the total rainfall upon the watershed and the per cent of this utilized by pumping at Ridgewood. The average yield utilized is also expressed in cubic feet per second per square mile of watershed. This was originally 49.9 square miles, but was increased in 1872, being in subsequent years 52.3 square miles until 1883, when it was increased to 64.6 square miles, and in 1885 to 65.4 square miles. Considerable additions were made in 1891, and from that time on the area is given as 154.1 square miles. In 1860 the rainfall was 37.65 inches, and the total amount of water pumped was equivalent to a depth of 1.44 inches on the watershed, or 3.82 per cent of the total rainfall. In 1896 the total rainfall was 38.82 inches. The amount of water pumped during that year would cover the watershed to a depth of 11 inches, this being over 28 per cent of the total rainfall. The average yield as obtained by pumping was 0.81 cubic foot per second per square mile of watershed.

Total annual rainfall, per cent utilized, and average yield per square mile of watershed of Brooklyn waterworks.

Year.	Rainfall in inches.	Per cent utilized.	Second-feet per square mile.	Year.	Rainfall in inches.	Per cent utilized.	Second-feet per square mile.
1860	37.65	3.82	0.11	1879	39.61	33.40	0.97
1861	45.65	3.92	0.13	1880	40.76	30.23	0.90
1862	38.02	5.73	0.16	1881	39.53	29.42	0.86
1863	32.76	8.39	0.20	1882	39.83	30.73	0.90
1864	32.00	10.53	0.25	1883	37.22	33.05	0.91
1865	46.14	8.39	0.28	1884	45.39	27.89	0.93
1866	51.68	8.88	0.34	1885	36.85	37.94	1.03
1867	54.61	9.39	0.38	1886	51.38	28.32	1.07
1868	38.58	17.29	0.49	1887	45.66	32.59	1.10
1869	43.13	17.20	0.55	1888	48.45	33.19	1.18
1870	39.25	19.82	0.57	1889	56.54	29.54	1.23
1871	51.26	15.78	0.60	1890	52.15	33.90	1.30
1872	39.75	23.47	0.67	1891	39.18	44.82	1.29
1873	47.99	20.88	0.74	1892	37.75	24.53	0.68
1874	45.83	21.49	0.73	1893	39.62	26.27	0.77
1875	40.90	26.89	0.81	1894	36.88	26.33	0.72
1876	41.77	27.08	0.83	1895	35.64	28.98	0.76
1877	40.18	30.29	0.90	1896	38.82	28.31	0.81
1878	48.66	25.15	0.90				

Generally the Brooklyn waterworks have not been so designed as to furnish records of the quantity drawn from these several different sources. There are also no records of the heights of the ground water at different points in the drainage area. If such were to be kept for a series of years, the records of the Brooklyn waterworks would possess a value not easily estimated. They would give a far more positive indication of the amount of water that can be drawn from such sandy areas than can now be gained from them. A few tests, however, of some of the driven-well plants have been made in the last few years.

At a test of the old driven-well plant at Spring Creek, made from October 22 to November 20, 1894, water was pumped at an average rate of 4,091,551 gallons in 24 hours. The elevation of the underside of the discharge valve of the pump was 12.3 feet above datum. On October 22, at the beginning of the tests, the average elevation of the water in the wells was 4 feet below datum. The quantity pumped in 24 hours, on October 22, was 4,488,275 gallons. On November 20, the date of the conclusion of the test, the elevation of water in wells was 7.7 feet below datum, and the quantity pumped on that day in 24 hours was 4,112,663 gallons. The total quantity pumped during the entire period from October 22 to November 20 was 122,746,525 gallons. The taking of this quantity of water from the wells resulted, therefore, in lowering the ground water a total of 3.7 feet.

A new driven-well plant at Watts Pond was subjected to a test of capacity extending continuously from January 3 to February 2, inclusive. In 1895 a rather extended series of tests were made of a number of the wells of the Brooklyn water supply in order to determine the yield as well as the extent of the underground supply. The following particulars of these tests have been derived from Mr. De Varona's report, as contained in the annual report of the commissioner of city works for the year 1895.[1]

The flowing wells at Jameco were tested from January 3 to 14, inclusive. During this period the wells were operated singly and in groups of 2, 3, and 4, in all possible combinations, and observations were taken to determine the elevation of the ground water. Upon completion of the tests a series of observations was taken, extending to January 30, to determine the normal water level. The results of these observations may be found in detail in De Varona's report. It was shown that the average yield from one well alone was only 1,000,000 gallons daily, decreasing pro rata up to a total yield of 3,500,000 gallons daily when four wells were in operation. The lowering of the ground water was approximately 5 feet when pumping 1,000,000 gallons, increasing up to approximately 10 feet when pumping at the full capacity developed of 3,500,000 gallons. In this connection it is stated that the water in these test wells is found to rise

[1] For a full account of the Brooklyn waterworks well systems see De Varona's History, etc.

and fall directly with the tide, thus rendering it difficult to state with accuracy the full effect of the pumping on the lowering of the water. To determine this point fully, De Varona states, would require a more prolonged series of observations than it was possible to make in 1895.

Another test was made at Jameco from December 9 to 20, 1895, inclusive. Between this date and the end of the previous tests an additional well had been sunk at Jameco to the depth of 160 feet. The average daily yield shown during the second test was, approximately, 1,000,000 gallons for a single well, with a proportionate increase for each well connected, the yield for five wells being, approximately, 5,000,000 gallons in 24 hours. The lowering of the water during those tests amounted to slightly over 14 feet at Jameco while pumping the 5,000,000 gallons daily from the five wells. The total amount of water pumped during the test was 61,239,555 gallons. The greatest lowering of the underground water level occurred at test well No. 8, where it amounted to 15.23 feet. At that time, when the water at Jameco was at its lowest level, the fall between test well No. 8 and test well No. 11 was 9.9 feet. The normal water level was not restored until twelve days after the tests had ceased.

The results obtained early in 1895 from the test made at Jameco of supplies from deep wells seemed to warrant further investigations as to the possibility of water from deep wells, and the report states that they have been carried on during the year. A series of test wells were driven, extending from the foot of the hill at Ridgewood reservoir to Forest Stream pumping station, each well being carried to a depth sufficient to determine the possibility of obtaining a deep supply from that point. The number of those wells sunk during that year was twelve, and the records of the strata passed through are given in Bulletin No. 138, referred to in the footnote.[1]

Returning to the table on page 194, it may be stated that the tributary drainage area in 1875, the first year for which statistics are given in the table, was 52.3 square miles. The drainage area remained at this figure until January, 1881, in which month, by the bringing of the Springfield pumping station into use, it was increased to 59.4 square miles. In the water year of 1875, with a total rainfall of 41.6 inches, the water utilized amounted to 10.78 inches, or to an average of 513,165 gallons per square mile per day, or to 0.79 of a cubic foot per square mile per second. In the water year of 1880, with a total rainfall of 40.04 inches, the water utilized amounted to 12.37 inches on the watershed, or to 587,568 gallons per square mile per day, or to 0.91 of a cubic foot per square mile per second. In 1881, with a rainfall of 41.52 inches, the total utilization of water amounted to 11.64 inches on the watershed, or to 554,473 gallons per square mile per day, or to 0.86 of a cubic foot per square mile per second. This drop in

[1] For the particulars of the geology of several of the Brooklyn waterworks wells, of which tests were made in 1895, see Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, 1896, pp. 23-37.

the unit of utilization merely shows the effect of the increase in the area of the watershed.

The tributary watershed remained at 59.4 square miles until August, 1883, in which month the Spring Creek and Baisley's driven-well stations were started. From this date the tributary drainage area is taken at 64.6 square miles. Spring Creek and Baisley's stations marked the beginning of the Brooklyn driven-well system. In the water year of 1884, with a total rainfall of 43.44 inches, the utilization was 12.53 inches, amounting to 594,992 gallons per square mile per day, or to 0.92 of a cubic foot per square mile per second.

In May, 1885, the Forest Stream and Clear Stream driven-well stations were started, thereby increasing the tributary drainage area to 65.4 square miles. In the water year of 1886, with a total rainfall of 50.43 inches, the water utilized amounted to 14.40 inches, equivalent to 685,521 gallons per square mile per day, or to 1.06 cubic feet per square mile per second.

The drainage area remained 65.4 square miles until June, 1890, when it was increased to 65.6 square miles by the addition of the Jameco Park driven-well station. In the water year 1891, with a total rainfall of 40.34 inches, the water utilized amounted to 18.48 inches on the watershed, equivalent to 879,811 gallons per square mile per day, or to 1.35 cubic feet per square mile per second.

Large extensions of the works were made in 1890 and 1891, so that with the beginning of pumping at Millburn on December 17, 1891, the tributary drainage area may be considered as increased from 65.6 to 154.1 square miles, an increase of 88.5 square miles. In the calendar year 1892, with a rainfall of 37.75 inches, the water drawn from the original watershed of 65.6 square miles amounted to 16.81 inches on the watershed, equivalent to 800,191 gallons per square mile, or to 1.24 cubic feet per second per square mile. The water drawn from the new watershed of 88.5 square miles that year amounted to 3.67 inches on the watershed, equivalent to 174,776 gallons per square mile per day, or to 0.27 of a cubic foot per square mile per second. In 1895, with a total rainfall of 35.64 inches, the original watershed of 65.6 square miles yielded 12.62 inches on the watershed, equivalent to 600,723 gallons per square mile per day, or to 0.93 of a cubic foot per square mile per second. The new watershed of 88.5 square miles furnished in that year 8.64 inches on the watershed, equivalent to 411,558 gallons per square mile per day, or to 0.64 of a cubic foot per square mile per second.

Summarizing the information in regard to the water yield of the sand plains of Long Island, it may be stated that the available data indicate a large yield. The streams of eastern New York can not be relied upon in their natural condition to yield more than about 0.3 of a cubic foot per square mile per second, while with an ordinary development of storage the limit may be usually placed at from 0.7

to 0.8 of a cubic foot per square mile per second, or at any rate at not much exceeding 1 foot per square mile per second. The sand deposits of Long Island may, therefore, be considered as great natural reservoirs from which, with proper development, large water supplies may be drawn, the same as from reservoirs artificially created on the earth's surface, these natural underground reservoirs possessing the advantage of furnishing a filtered water of high purity.

INDEX TO PAPERS NOS. 24 AND 25.

Page.

Adirondack Plateau, water yield of 16–18
Allegheny Mountains, water yield of 16
Allegheny River, hydrography of 44
Anchor ice, obstruction from 14, 190–191
Ausable River, fall of 32
Battenkill River, hydrography of 40–41
  power of 41
Black River, hydrography of 29–30, 96–97
Black River Canal, cost and revenues of .. 154–158
  length and capacity of 158
Black Rock, water power at 178–179
Brooklyn, water supply of 15, 43, 47, 191–195
Buffalo Creek, course of 24
Canadaway Creek, power of 24
Canals, construction of 145–150
  cost and revenues of 154–155
  improvement of 155–157
  transportation by 150–154
  water supply of 158–161, 164–166, 173–178
  See Ship canals.
Canaseraga Creek, course of 25
Catskill Mountains, water yield of 16
Cayuga and Seneca Canal, construction of 149
  cost and revenues of 154
Cayuga Lake, drainage area of 28
Champlain Canal, construction of 148–149
  cost and revenues of 154–157
  length and capacity of 157, 158
  water supply of 159–161
Chateaugay River, course of 30
Chemung Canal, construction of 149
  cost and revenues of 154–155
Chemung River, drainage area of 88
  floods in 12, 87–90
Chenango Canal, construction of 149
  cost and revenues of 154–155, 157–158
  length and capacity of 157–158, 161–165
  loss of water in 174–175
Chenango River, course of 45
Chicago drainage canal, water diverted through 62
Clyde River, drainage area of 28
Cohocton River, course of 45
Cohoes, water power at 35, 185–186
Crooked Lake Canal, construction of 149
  cost and revenues of 154–155
Croton River, hydrography of 12, 33, 82–86, 98
  storage on 86–87
Deforestation, effects of 11, 12, 14, 16–17
Delaware River, hydrography of 46–47
Des Plaines River, hydrography of .. 54–55, 64–65

Page.

East Canada Creek, hydrography of 36–37
  power of 37–38
Eaton Brook, hydrography of 67, 68
Erie Canal, construction of 13, 147–150
  cost and revenues of 154, 157
  improvement of 155–156, 169–171
  length and capacity of 157, 158, 161–165
  transportation on 13–14, 150–154
  water power of 178–184
  water supply of 158–161, 164–166, 173–178
Fish Creek, fall of 36
Fish Creek, power of 41
Floods, occurrence of 12, 72–73, 87
Forests, influence of 16–18
Frazil, obstruction from 14, 190–191
Fredonia, stream measurements near 95
Genesee River, flood on 112–113
  hydrography of 11, 25–27, 57, 58, 70–75, 90–92
  power of 109, 123–125
  storage on 12, 109–125
  tributaries of 25–26
Genesee Valley Canal, cost and revenues of 154–155
Grass River, course of 30
Great Lakes, discharge of 58
  drainage area of 48
  precipitation on drainage area of 49–53, 58
Hemlock Lake, hydrography of .. 12, 75–77, 92–93
Honeoye Creek, power of 26
Hoosic River, hydrography of 40
  power of 40
  storage on 40
Hudson River, commerce of 144–145
  hydrography of 33–34, 79–82, 97–98
  logging on 14
  precipitation on drainage area of 133
  storage on 12, 125–134
  tributaries of 33–43
Jameco, wells at 195–196
Kayaderosseras Creek, power of 41
Lake Champlain, streams tributary to 31–33
Lake Erie, altitude of 59
Lake Ontario, drainage area of 65
Little Falls, water power at 35
Lockport, water power at 179–182, 186
Long Island, hydrography of 14–15, 47, 191–198
Low-water flow of streams 90–99
Lumber, transportation of 14
Madison Brook, hydrography of 67, 68, 69
Massena, power development at 12, 143–144
Mechanicville, stream measurements at .. 81–82
Medina, water power at 182–184

Page.

Mohawk River, hydrography of 35, 97
tributaries of 35–40
Morris Run, discharge of 93–94
Mount Morris, proposed reservoir at 110, 113–114, 117, 122–125
stream measurements at 58, 72–73, 91
Muskingum River, hydrography of 55–57
Neversink Creek, course of 46
Newell, F. H., letters of transmittal by .. 7, 107
Niagara Falls, power development at 12, 135–143, 186
Niagara River, hydrography of 11, 24–25, 48, 59–63
power development on 12, 135–143
Oatka Creek, hydrography of 69–70, 90
Oneida River, drainage area of 29
Oriskany Creek, course of 40
Oswegatchie River, course of 30
Oswego, water power at 184–185
Oswego Canal, construction of 149
cost and revenues of 154, 157
length and capacity of 157
Oswego River, hydrography of 27–29, 96
power of 29
Owasco Lake, drainage area of 28
Ownership of water 10, 14–15, 186–188
Paper, manufacture of 14
Pepacton River, course of 46
Portage, proposed reservoir at 114–125
stream measurements at 119–121
Precipitation, amount of 19–21
Price of water power 184–186
Raquette River, course of 30
Rochester, stream measurements at 72, 76–77, 91, 119
water power at 186
Rome, water supply of 35

Page.

Sacundaga River, hydrography of 42
storage on 128, 131
St. Lawrence River, hydrography of 65–66
power development on 12, 143–144
tributaries of 24–31
St. Regis River, course of 30
Saranac River, fall of 32
Sauquoit Creek, course of 40
Schoharie Creek, hydrography of 35–36
Schroon River, hydrography of 43
storage on 129
Seneca Lock Navigation Company, operations of 147
Seneca River, drainage area of 28
Ship canals, proposed routes for 166–173
Skaneateles Lake, hydrography of 77–78, 96
Spruce Creek, fall of 37
Storage reservoirs, advantages of 12, 111–112, 132–134
canals supplied by 164–166
capacity and cost of 116–117, 130–131
sites for 109–111, 113–125
Susquehanna River, hydrography of 44–46
Syracuse, stream measurements at 77–78
Temperature, variations in 18–19
Tioga River, course of 45
Tonawanda Creek, course of 24
Topography, character of 16–18, 21–23
Upper Mississippi reservoirs, discharge of 53–54
Warsaw, stream measurements at 93–94
West Branch of Canadaway Creek, discharge of 94–95
West Canada Creek, hydrography of 38–39
power of 39
Western Inland Lock Navigation Company, operations of 146

1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Bighorn Range and Bighorn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett; and "Preliminary report on the artesian areas of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton; and "Reservoirs for irrigation," by J. D. Schuyler.

1898.

Nineteenth Annual Report of the United States Geological Survey, 1897–98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1897," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton; and "Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

WATER-SUPPLY AND IRRIGATION PAPERS, 1896–1899.

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17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
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21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems in the Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.

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